

TECHNICAL RESOURCE DOCUMENT

EXTRACTION AND BENEFICIATION OF ORES AND MINERALS

VOLUME 1

LEAD-ZINC

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Office of Solid Waste
Special Waste Branch
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Washington, DC 20460**



DISCLAIMER AND ACKNOWLEDGEMENTS

This document was prepared by the U.S. Environmental Protection Agency (EPA). The mention of company or product names is not to be considered an endorsement by the U.S. Government or the EPA.

This Technical Resource Document consists of two sections. The first section is EPA's Profile of the lead-zinc industry; the remaining section is a Site Visit Report from a site visit conducted by EPA. The Profile Section was distributed for review to the U.S. Department of the Interior's Bureau of Mines, the Western Governors Association, the Interstate Mining Compact Commission, the American Mining Congress, and Public Interest Groups. Summaries of the comments and EPA's responses are presented as an appendix to the Profile Section. The Site Visit Report Section was reviewed by individual company, state, and Federal representatives who participated in the site visit. Comments and EPA responses are included as Appendices to the specific Site Visit Section. EPA is grateful to all individuals who took the time to review sections of this Technical Resource Document.

The use of the terms "extraction," "beneficiation," and mineral processing" in the Profile section of this document is not intended to classify any waste streams for the purposes of regulatory interpretation or application. Rather, these terms are used in the context of common industry terminology.

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1.0 MINING INDUSTRY PROFILE: LEAD-ZINC

1.1 INTRODUCTION

This Industry Profile presents the results of the Environmental Protection Agency's (EPA's) research into the domestic lead-zinc mining industry and is one of a series of profiles of major mining sectors. Additional profiles describe copper mining, gold mining, iron mining, and several industrial mineral sectors, as presented in the current literature. EPA prepared these profiles to enhance and update its understanding of the mining industry and to support mining program development by the states. EPA believes the profiles represent current environmental management practices as described in the literature.

Each profile addresses extraction and beneficiation of ores. The scope of the Resource Conservation and Recovery Act (RCRA) as it applies to mining waste was amended in 1980 when Congress passed the Bevill Amendment, Section 3001(b)(3)(A). The Bevill Amendment states that "solid waste from extraction, beneficiation, and processing of ores and minerals" is excluded from the definition of hazardous waste under Subtitle C of RCRA (40 CFR 261.4(b)(7)). The exemption was conditional upon EPA's completion of studies required by RCRA § 8002(f) and (p) on the environmental and health consequences of the disposal and use of these wastes. EPA segregated extraction and beneficiation wastes from processing wastes. EPA submitted the initial results of these studies in the *1985 Report to Congress: Wastes from the Extraction and Beneficiation of Metallic Ores, Phosphate Rock, Asbestos, Overburden from Uranium Mining and Oil Shale* (U.S. EPA, 1985). In July 1986, EPA made a regulatory determination that regulation of extraction and beneficiation wastes under Subtitle C was not appropriate (51 FR 24496; July 3, 1986). EPA concluded that Subtitle C controls were unnecessary and found that a wide variety of existing Federal and State programs already addressed many of the risks posed by extraction and beneficiation wastes. Instead of regulating extraction and beneficiation wastes as hazardous wastes under Subtitle C, EPA indicated that these wastes should be controlled under Subtitle D of RCRA.

EPA reported their initial findings on mineral processing wastes from the studies required by the Bevill Amendment in the *1990 Report to Congress: Special Wastes from Mineral Processing* (U.S. EPA, 1990). This report covered 20 specific mineral processing wastes. In June 1991, EPA issued a regulatory determination (56 FR 27300) stating that regulation of these 20 mineral processing wastes as hazardous wastes under RCRA Subtitle C is inappropriate or unfeasible. Eighteen of the wastes, including slag from primary lead processing and slag from primary zinc processing are subject to applicable state requirements. The remaining two wastes (phosphogypsum and phosphoric acid process waste water) are currently being evaluated under the authority of the Toxic Substances Control Act (TSCA) to investigate pollution prevention alternatives. Any mineral processing wastes not specifically included in this list of 20 wastes no longer qualifies for the exclusion (54 FR 36592).

Due to the timing of this decision and the limited numbers of lead-zinc industry wastes at issue, lead-zinc processing wastes are not addressed in this profile.

In addition to preparing profiles, EPA has undertaken a variety of activities to support state mine waste programs. These activities include visiting a number of mine sites; compiling data from State regulatory agencies on waste characteristics, releases, and environmental effects; preparing summaries of mining-related sites on the National Priorities List (NPL); and examining specific waste management practices and technologies. EPA has also conducted studies of State mining-related regulatory programs and their implementation.

The purpose of this profile is to provide additional information on the domestic lead-zinc mining industry. The report describes lead-zinc extraction and beneficiation operations with specific reference to the wastes associated with these operations. The report is based on literature reviews and on comments received on earlier drafts. This report complements, but was developed independently of, other Agency activities, including those described above.

This report briefly characterizes the geology of lead-zinc ores and the economics of the industry. Following this discussion is a review of lead-zinc extraction and beneficiation methods; this section provides the context for descriptions of wastes and materials managed by the industry, as well as a discussion of the potential environmental effects that may result from lead-zinc mining. The report concludes with a description of the current regulatory programs that apply to the lead-zinc mining industry as implemented by EPA, Federal land management agencies, and selected states.

1.2 ECONOMIC CHARACTERIZATION OF THE INDUSTRY

1.2.1 Lead

Domestic production of lead concentrates in 1989 was 420,000 metric tons. Domestic lead concentrate production in 1990 increased to 495,000 metric tons (U.S. DOI, Bureau of Mines, 1991; 1992). The United States is the world's largest primary lead producer with 1/5 of all production and reserves. About 1/2 of the domestic lead demand is met by recycling lead from secondary sources (scrap), rather than primary sources (mining) (U.S. DOI, Bureau of Mines, 1990). Approximately 874,000 metric tons of lead were recovered from scrap sources. Total consumption of lead in 1989 was reported to be approximately 1.3 million metric tons. (U.S. DOI, Bureau of Mines, 1992).

Historically, lead has been mined in 12 states: Arizona, California, Colorado, Idaho, Illinois, Missouri, Montana, Nevada, New Mexico, New York, Tennessee, and Utah. In 1988, however, lead ore was not mined in California or Utah. According to the U.S. Bureau of Mines, Missouri produced over 90 percent of all domestic lead in 1988. Table 1-1 is a list of active lead and zinc mines in the United States as of 1990. Information provided includes mine owners, mine operators, commodities produced, production data, ore reserves, and ore grade. These mines account for nearly all domestically-produced primary lead (Michaelis, 1990/1991; Gardiner, 1990).

In 1989, the lead industry employed 1,800 workers at mines and mills, 800 at primary smelters and refineries, and 1,700 at secondary smelters and refineries. For 1990, employment figures were expected to increase to 2,100 workers at mines and mills and 1,800 at secondary smelters and refineries. Primary smelter and refinery employment was not expected to change in 1990 (U.S. DOI, Bureau of Mines, 1991).

Refined lead is used in a variety ways: for bearing or casting metal; as sheet lead; solder; oxide; and in storage batteries. Major domestic uses of lead, by product and SIC code, are listed in Table 1-2 (U.S. DOI, Bureau of Mines, 1990a). In 1989, transportation was the most common end use for lead products, accounting for 75 percent of all lead produced. This included automotive batteries, as well as solders, seals, and bearings. Electrical uses, electronics, ammunition, TV glass, building construction, communications, and protective coatings (including radiation shielding) accounted for an additional 20 percent of production. Currently, lead is also used in ballast weights, ceramics, crystal glass, tubes or containers, type metal, foil, and wire (U.S. DOI, Bureau of Mines, 1991).

1.2.2 Zinc

In 1990, U.S. zinc mining operations extracted 515,000 metric tons of recoverable zinc, valued at \$847 million; an increase of 239,000 metric tons over that produced in 1989. The amount of zinc from scrap sources decreased slightly (from 117,000 to 109,000 metric tons) for the same period (U.S. DOI, Bureau of Mines, 1992).

Table 1-1. Characteristics of Lead and Zinc Mines

State	Mine Name	Location	Owner(s) [Operator]	Commodities Produced*	Lead-Zinc Production 1988 (tons concentrate/year)	Ore Reserves (tons) Ore Grade (per ton ore)
AK	Greens Creek Mine (Startup 1989)	Admiralty Island	Kennecott: 53% Hecla Mining: 28% Exalas Resources: 12.6% CSX Oil & Gas: 6.3% [Greens Creek Mining]	Gold Silver Zinc Lead	(Projected) Pb - 8,000 Zn - 23,000	3,500,000 0.18 oz Au 3.9% Pb 9.7% Zn 24 oz Ag
AK	Red Dog Mine (Startup 1989)	Kotzebue	Cominco American, Inc., NANA Regional Corp. [Cominco Alaska, Inc.]	Lead Zinc Silver	(Expected) Zn - 560,000 Pb - 120,000	85,000,000 5.0% Pb 17.1% Zn 2.4 oz Ag
CO	Asarco Leadville Unit (Resurrection Mine, Black Cloud Mine)	Lake County (Leadville)	Asarco, Inc.: 50% Resurrection Mining Co., Newmont: 50% [Asarco, Inc.]	Lead Zinc Gold Silver	Pb - 7,000 Zn - 14,900	841,000 tons 3.37% Pb 8.41% Zn 1.9 oz Ag 0.06 oz Au 0.19% Cu
CO	Sunnyside Mine	San Juan County (Silverton)	San Juan County Mining Venture: Washington Mining Co. 33%, Alta Bay Venture (Echo Bay, Alta Gold) 67% [Washington Mining Company]	Gold Silver Lead Zinc Copper	N/A	627,000 tons 0.15 oz Au 4.2% Pb 6.2% Zn 0.57% Cu

* Commodities presented in order of listing in Randol Directory.

Sources: Michaelis, 1990/1991; Gardiner, 1990

Table 1-1. Characteristics of Lead and Zinc Mines (Continued)

State	Mine Name	Location	Owner(s) [Operator]	Commodities Produced*	Lead-Zinc Production 1988 (tons concentrate/year)	Ore Reserves (tons) Ore Grade (per ton ore)
ID	Fourth of July Mine	Valley County (Yellow Pine)	[American Ind. Mines & Minerals Corp.]	Silver Lead Gold Tungsten	N/A	N/A
ID	Galena Mine	Shoshone County (Mullan)	Callahan Mining Corp.: 50% Asarco Inc.: 37% Hecla Mining Co.: 13%	Silver Lead Copper Zinc Gold	N/A	1,239,000 16.39 oz Ag 10.04% Pb 0.57% Cu 0.11% Zn
ID	Lucky Friday Mine	Shoshone County (Mullan)	Hecla Mining Company: 100% [Hecla Mining Company]	Silver Gold Zinc Lead	Pb - 12,675 Zn - 2,301	598,200 15.4 oz Ag 13.0% Pb 2.3% Zn N/A Au
MO	Magmont Mine	Iron County (Bixby)	Cominco Ltd.: 50% Dresser Industries, Inc.: 50% [Cominco American Incorporated]	Lead Zinc Copper	Pb - 99,000 Zn - 15,000	3,690,000 7.5% Pb 1.2% Zn 0.3% Cu

* Commodities presented in order of listing in Randol Directory.

Sources: Michaelis, 1990/1991; Gardiner, 1990

Table 1-1. Characteristics of Lead and Zinc Mines (Continued)

State	Mine Name	Location	Owner(s) [Operator]	Commodities Produced*	Lead-Zinc Production 1988 (tons concentrate/year)	Ore Reserves (tons) Ore Grade (per ton ore)
MO	Sweetwater Mine	Reynolds County (Bunker)	Asarco, Inc.: 100% [Asarco, Inc.]	Lead Zinc	Pb - 20,900 Zn - 1,600	24,967,000 4.84% Pb 0.59% Zn
MO	Viburnum Mines (6 mines): Brushy Creek Casteel Fletcher Viburnum 28 Viburnum 29 Buick	Iron, Reynolds, and Washington Counties	The Doe Run Company [Subsidiary of the Fluor Corporation]	Lead Zinc Copper	Pb - 326,515 Zn - 46,416	73,0749,000 5.1% Pb 0.9% Zn 0.3% Cu
MO	West Fork Mine	Reynolds County (Bunker)	Asarco, Inc.: 100% [Asarco, Inc.]	Lead Zinc	Pb - 49,000 Zn - 11,900	10,295,000 5.93% Pb 1.47% Zn 0.04% Cu 0.30 oz Ag
MT	Montana Tunnels Mine	Jefferson County	Montana Tunnels Mining Co. (Pegasus Gold, Inc.): 100% [Montana Tunnels Mining Co.]	Gold Silver Lead Zinc	Zn - 18,400 Pb - 8,400	37,370,000 0.021 oz Au 0.36 oz Ag 0.63% Zn 0.23% Pb

*Commodities presented in order of listing in Randol Directory.

Sources: Michaelis, 1990/1991; Gardiner, 1990

Table 1-1. Characteristics of Lead and Zinc Mines (Continued)

State	Mine Name	Location	Owner(s) [Operator]	Commodities Produced*	Lead-Zinc Production 1988 (tons concentrate/year)	Ore Reserves (tons) Ore Grade (per ton ore)
NM	Cyprus Pinos Altos (Zn start-up 1990)	Grant County (Silver City)	Cyprus Copper Co.: 50% St. Cloud Mining Co. (The Goldfield Corp.): 50% [Cyprus Pinos Altos Corp.]	Copper Zinc Silver	(Projected) Zn - 2,500 to 3,000	800,000 4.9% Cu
NY	Balmat Mine No. 2 Balmat Mine No. 4 Pierrepoint Mine No. 4	St. Lawrence County	Horsehead Industries [Zinc Corporation of America]	Zinc	N/A	3,900,000 Grades N/A
OR	Silver Butte Mine (Under construction.)	Douglas County	Formosa Exploration Inc.: 100% [Formosa Exploration Inc.]	Gold Silver Copper Zinc	N/A	460,000 3.40% Cu 2.83% Zn
TN	Coy Mine	Jefferson County	Asarco, Inc.: 100% [Asarco, Inc.]	Zinc	Zn - 74,800 (Includes New Market, Young, and Immel Mines)	6,398,000 3.23% Zn

*Commodities presented in order of listing in Randol Directory.

Sources: Michaelis, 1990/1991; Gardiner, 1990

Table 1-1. Characteristics of Lead and Zinc Mines (Continued)

State	Mine Name	Location	Owner(s) [Operator]	Commodities Produced*	Lead-Zinc Production 1988 (tons concentrate/year)	Ore Reserves (tons) Ore Grade (per ton ore)
TN	Elmwood- Gordonsville Mine	Smith County	Jersey Miniere Zinc: 100% (Union Zinc) [Jersey Miniere Zinc]	Zinc	N/A	N/A (1,600,000 tpy ore)
TN	Immel Mine	Knox County	Asarco, Inc.: 100% [Asarco, Inc.]	Zinc	See Coy Mine.	See Coy Mine. (863,322 tpy ore)
TN	New Market Mine	Jefferson County	Asarco, Inc.: 100% [Asarco, Inc.]	Zinc	See Coy Mine.	See Coy Mine. (732,000 tpy ore)
TN	Young Mine (including former Beaver Mine)	Jefferson County	Asarco, Inc.: 100% [Asarco, Inc.]	Zinc	See Coy Mine.	See Coy mine. (1,151,100 tpy ore)
WA	Glass Mine (start-up 1990)	Pend Oreille County	 [Raven Hill Mining]	Lead	N/A	N/A
WA	Schumaker Mine (start-up 1990)	Stevens County (Colville)	Cordilleran Mines [General Mine Services Corp.]	Zinc	N/A	100,000 10.0% Zn

N/A Not available.

*Commodities presented in order of listing in Randol Directory.

Sources: Michaelis, 1990/1991; Gardiner, 1990

Table 1-2. United States Consumption of Lead, By Product
(In Metric Tons)

SIC Code	Product	1988	1989
	Metal Products		
3482	Ammunition: Shot and bullets	52,708	62,940
	Bearing Metals		
35	Machinery except electrical	425	W
36	Electrical and electronic equipment	(*)	W
371	Motor vehicles and equipment	5,152	1,683
37	Other transportation equipment	457	W
	Total bearing metals	6,034	2,586
3351	Brass and bronze: Billets and ingots	9,994	9,610
36	Cable covering: Power and communication	16,170	22,605
15	Calking lead: Building construction	1,618	1,831
	Casting Metals:		
36	Electrical machinery and equipment	1,333	524
371	Motor vehicles and equipment	(*)	W
37	Other transportation equipment	13,474	3,395
3443	Nuclear radiation shielding	1,065	W
	Total casting metals	15,872	16,175
	Pipes, casts and other extruded products:		
15	Building construction	11,193	8,856
3443	Storage tanks, process vessels, etc.	(*)	962
	Total pipes, traps, other extruded products	11,193	9,818
	Sheet lead:		
15	Building construction	14,009	15,900
3443	Storage tanks, process vessels, etc.	(*)	(*)
	Total sheet lead	17,458	20,987

Table 1-2. United States Consumption of Lead, By Product (Continued)

SIC Code	Product	1988	1989
	Sheet lead:		
15	Building construction	14,009	15,900
3443	Storage tanks, process vessels, etc.	(^c)	(^c)
	Total sheet lead	17,458	20,987
	Solder:		
15	Building construction	3,985	3,909
341	Metal cans and shipping containers	848	762
367	Electronic components and accessories	4,824	4,092
36	Other electrical machinery and equipment	3,052	2,029
371	Motor vehicles and equipment	6,355	6,217
	Total solder	19,064	17,009
	Storage batteries:		
3691	Storage battery grids, post, etc.	514,694	552,308
3691	Storage battery oxides	454,964	459,847
	Total storage batteries	969,658	1,012,155
371	Terne metal: Motor vehicles and equipment	2,324	2,286
27	Type metal: Printing and allied industries	(^c)	(^c)
34	Other metal products ^d	5,290	4,564
	Total metal products	1,127,383	1,182,566
	Other oxides:		
285	Paints	W	W
32	Glass and ceramic products	W	W
28	Other pigments and chemicals	W	10,074
	Total other oxides	62,524	57,984
2911	Gasoline additives	(^c)	(^c)
	Miscellaneous uses	55,263	42,684
	Grand total	1,245,170	1,283,234

^c Revised. ^W withheld to avoid disclosing company proprietary data; included in "Total other oxides."

^a Included with "Other transportation equipment" to avoid disclosing company proprietary data.

^b Included with "Building construction" to avoid disclosing company proprietary data.

^c Included with "Other metal products" to avoid disclosing company proprietary data.

^d Includes lead consumed in foil, collapsible tubes, annealing, galvanizing, plating, and fishing weights.

^e Included with "Miscellaneous uses" to avoid disclosing company proprietary data.

Note: Totals may not add because of withheld information.

Source: U.S. DOI, Bureau of Mines, 1990b

Historically, recoverable zinc has been mined in 18 states: Arizona, Colorado, Idaho, Illinois, Kansas, Missouri, Montana, Nevada, New Jersey, New Mexico, New York, Oklahoma, Pennsylvania, Tennessee, Utah, Virginia, Washington, and Wisconsin. In 1988, however, no zinc ore was extracted in New Jersey, Pennsylvania, or Utah, and nearly 50 percent of all domestic zinc was produced in Tennessee. Other known state production figures include Missouri (17 percent) and Montana (8 percent). Table 1-1 is a list of active lead and zinc mines in the United States as of 1990. Information provided in the table includes mine owners, operators, commodities produced, production data, ore reserves, and ore grade (Michaelis, 1990/1991; Gardiner, 1990).

In 1989, the zinc industry employed 2,350 workers at mines and mills and 1,500 at primary smelters. For 1990, mine and mill employment was expected to grow to 2,600 and employment at zinc smelters was expected to increase to 1,550 (U.S. DOI, Bureau of Mines, 1991). Employment increases in mines and mills may be attributed to opening new mines, such as the Red Dog Mine in Alaska.

Zinc products are used in several major industries, including construction (45 percent of 1988 consumption for galvanizing and steel manufacturing); transportation (23 percent); machinery manufacturing (12 percent); electrical (10 percent); and chemical and other industries (10 percent) (U.S. DOI, Bureau of Mines, 1990b).

Zinc has a number of properties that make it valuable to industry. These include a low melting point, high electrochemical activity to protect iron and steel materials from cathodic corrosion, and the ability to alloy with copper to make brass (U.S. DOI, Bureau of Mines, 1985b). Galvanizing and electrogalvanizing (steel coating) were the principal uses of refined zinc in 1988, accounting for 51 percent of all zinc use. Zinc was also used extensively in zinc-based die-cast alloys (23 percent) and brass alloys (13 percent). The remaining 13 percent of zinc consumption was used for alloys, rolled zinc, dust, and oxide (U.S. DOI, Bureau of Mines, 1990b).

Zinc oxide is well suited for use in rubber, paints, inks, dyes, oil additives, wood preservatives, fungicides, varnishes, and linoleums. Zinc oxide is used in these products because of its opacity to ultra-violet light and high refractory index, durability, and electrostatic properties (U.S. DOI, Bureau of Mines, 1985b).

1.3 ORE CHARACTERIZATION

Lead and zinc most often occur in association with the sulfide mineral group. Other metals associated with sulfide ores include copper, iron, mercury, arsenic, cadmium, silver, and small quantities of gold. These metals occur in varying amounts with lead and zinc ores. Galena (PbS) and sphalerite (ZnS) are the principal minerals mined to recover lead and zinc, respectively.

Deposits that contain more than one of these recoverable metals are referred to as "polymetallic ores," and are described by the dominant economic metal being recovered, followed by lesser constituents. For example, a mine producing mainly lead and some zinc is referred to as a "lead-zinc mine." Similarly, a zinc-copper mine produces mainly zinc and some copper. The individual metal content is dependent on the nature of the ore body. In the United States today, minable quantities of lead and zinc ore are recovered from three types of deposits: strata-bound deposits, replacement deposits, and vein deposits.

The largest and most productive lead and zinc ore deposits are associated with expansive, relatively flat lying sedimentary deposits. Strata-bound deposits, as the name implies, are restricted to well-defined stratigraphic units, typically limestone, dolomite, or shale. In strata-bound deposits, the metal-bearing minerals may be deposited either during or long after deposition of the host limestone or dolomite. Deposits that form during or shortly following deposition are referred to as strata-bound deposits of syngenetic origin; those that form long after lithification of the sediments are referred to as strata-bound deposits of epigenetic origin. Most geologists agree that the origin of the lead and zinc bearing minerals in southeast Missouri are of epigenetic origin. Strata-bound ore deposits are typically capped by fine-grain sediments, such as shales. The cap rock acts to contain the migrating mineral bearing hydrothermal fluids. Minerals precipitate in the host rock as a result of changes in chemistry, temperature, and pressure.

The best known strata-bound deposits in the United States are the Mississippi Valley type, such as those found in Missouri and Tennessee, and the relatively recent discovery in the DeLong Mountains of Alaska. Most notable of these are the lead-zinc ores of the Viburnum Trend (also referred to as the "New Lead Belt") in southeast Missouri and the zinc-lead ores of the Red Dog deposit in Alaska. Ore grades for the Viburnum Trend deposits range between 5 and 10 percent lead, up to 1 percent zinc, with lesser amounts of copper, silver, nickel, cobalt, cadmium, and silver. Mineral assemblages found at the Buick mine are typical of the Viburnum Trend and include galena, sphalerite, chalcopryite (CuFeS_2), pyrite (FeS_2), calcite (CaCO_3), and dolomite ($\text{CaMg}(\text{CO}_3)_2$). The Red Dog deposit is considered to be the largest or second largest zinc-lead deposit in the world. Mineralization occurs in black shales of late Mississippian to Permian age. It is a strata-bound accumulation of silica rock, barite, and sulfides; dominant gangue minerals are quartz and barite (U.S. DOI, Geological Survey, 1973 a and b; Weiss, 1985; Kral, 1992).

Replacement and vein type deposits make up a smaller portion of mined lead and zinc ores. Historically, however, these kinds of deposits were the primary source of ore. These deposits form when hydrothermal solutions containing metals migrate through vein and porous rock and eventually precipitate as a result of changes in chemistry, temperature, and pressure. Host rocks vary greatly and include sedimentary carbonates as well as igneous and metamorphic rocks. Examples of replacement deposits mined as ores are found in Bingham, Utah, and Gilman and Leadville, Colorado. Examples of vein deposits are those found in the Coeur d'Alene district of Idaho. Typical ore grades are on the order of 10 to 30 percent lead and zinc combined, 3 to 5 percent copper, and smaller quantities of silver and gold. Common mineral assemblages include galena, sphalerite, chalcopyrite (CuFeS_2), and pyrite (FeS_2). Associated with these deposits are elements such as silver, arsenic, antimony, and cadmium.

Other sources of zinc ores are associated with metamorphic rocks. Examples of these are the Ducktown district of Tennessee, the Balmat-Edwards district of New York, and the Franklin Furnace-Sterling Hill district of New Jersey. To date, the New York and New Jersey districts have produced seven million tons of zinc; however, New Jersey is not currently producing measurable quantities of zinc. Significant reserves remain in these districts. The Franklin zinc deposit in New Jersey is unique in that the minerals are predominantly franklinite ($(\text{Zn})(\text{Fe},\text{Mn})_2\text{O}_4$), willemite (Zn_2SiO_4), and zincite (ZnO). Tennessee continues to produce significant quantities of zinc.

1.4 LEAD-ZINC EXTRACTION AND BENEFICIATION PRACTICES

Lead and zinc operations consists of three major operational steps: extraction, beneficiation, and processing. Extraction is defined as removing ore material from a deposit and encompasses all activities prior to beneficiation. Beneficiation of lead and zinc ores includes crushing, grinding, washing, filtration, sorting, sizing, gravity concentration, and flotation concentration (40 CFR 261.4). Processing activities follow beneficiation and include smelting and refining of concentrates to prepare a marketable lead or zinc product. This profile only discusses extraction and beneficiation activities. A discussion of wastes generated from mineral processing is found in EPA's 1990 Report to Congress, *Special Wastes from Mineral Processing*.

Material associated with lead-zinc mining may consist of the ore itself, mine development rock (in the case of underground mines), and overburden (in the case of surface mines). Mine development rock is the material removed while constructing shafts, adits, and drifts, or preparing access to the ore body (Weiss, 1985). Overburden consists of soil and rock material that overlies the mine area. Industry collectively refers to these materials as waste rock. A summary of the quantities of material handled, waste, and crude ore, and marketable product generated at lead and zinc mines in 1987 (as reported by the U.S. Bureau of Mines) is presented in Table 1-3. Also presented in this table are associated production ratios.

Table 1-3. Waste to Product Ratios, Crude Ore to Product Ratios, and Material Handled to Product Ratios For Lead and Zinc, 1987

Material/Ratio	Lead (1,000 short tons)	Zinc (1,000 short tons)
Material Handled	8,670	5,230
Crude Ore	5,800	5,180
Waste	2,870	50
Marketable Product	290 (units)	169 (units)
Waste to Marketable Product Ratio	9.9:1	0.3:1
Crude Ore to Marketable Product Ratio	20.9:1	30.7:1
Material Handled to Marketable Product Ratio	29.9:1	30.9:1

Source: U.S. DOI, Bureau of Mines, 1990a; 1990b

1.4.1 Extraction Methods

Lead and zinc are mined almost exclusively in underground operations although a few surface operations do exist. For example, the Red Dog Mine in Alaska, which began production in August 1990, employs open-pit mining techniques (Alaska Division of Geological and Geophysical Surveys, 1989). The decision to use underground or surface mining techniques is dependent on the proximity of the ore body to the surface. Lead-zinc underground mining techniques use shafts, drifts, and adits to access the ore body. The most common underground mining method to remove the ore is room-and-pillar. (U.S. DOI, Bureau of Mines, 1984; 1985a). Room-and-pillar techniques are commonly used to extract lead-zinc ore from large, flat-lying, tabular-shaped, strata-bound deposits. This mining style is employed to extract the ores in southeast Missouri. In contrast, extraction of ore from vein-type deposits is best suited to more selective stope mining methods. Stope mining involves the driving of horizontal shafts into the ore body, one above the other. Stoping was used in the mines near Leadville, Colorado. The exact mining method used is determined by the individual characteristics of each ore body.

In general, underground mining operations involve sinking a shaft near the ore body to be extracted and extending horizontal passages (levels) from the main shaft at various depths to the ore. Ore is removed from the mine either through shaft conveyances or chutes. In some cases, waste rock or classified mill tailings are returned to the mine and used to backfill mined-out areas (U.S. EPA, Office of Water, 1982).

Profitable recovery of lead-zinc ores ranges from as low as 3 percent metal in ore for large, easily accessed mines, to 6 percent for small, difficult-to-access underground mines, to more than 10 percent for extremely high-cost, remote areas. The Red Dog Mine concentrator (in the Delong Mountains in northwestern Alaska) is expected to mill ore averaging 5 percent lead and 17.1 percent zinc (Sastry, 1988). Low grade lead and zinc ores can also be mined profitably when produced as a byproduct of copper mining, or when appreciable quantities of precious metals (such as silver) are present (Weiss, 1985). Few lead-zinc deposits contain more than 50 million tons of ore.

1.4.2 Beneficiation Methods

Beneficiation of lead and zinc ores begins with milling (crushing and grinding). Following these steps, the ore is further beneficiated by flotation. Before the advent of flotation in the early 1900s, gravity concentration was the chief method by which lead-zinc ores were concentrated. As a result of more selective reagents and advancements in grinding techniques, flotation has virtually replaced gravity concentration. Gravity concentration techniques, however, may still be used for preconcentrating before fine grinding and flotation (U.S. DOI, Bureau of Mines, 1984; 1985a).

1.4.2.1 Milling

Beneficiation starts with the milling of extracted ore in preparation for further activities to recover the lead and zinc values. Milling operations are designed to produce uniformly sized particles by crushing, grinding, and wet or dry classification. The capital investment and operation costs of milling equipment are high. For this reason, economics plays a large part in determining the type of milling (or comminution) equipment and the degree of crushing or grinding performed to prepare the ore for further beneficiation. Other factors include the value concentration of the ore and its mineralogy (especially the presence or absence of pyrite), hardness, and moisture content. Milling procedures vary widely both between mills and within individual mills, depending on these variables (White and Clifford, 1977).

Milling is a multistaged operation of crushing and grinding. Crushing is usually a dry operation, using water sprays only to control dust. Frequently, a primary crusher (jaw crusher) is located at the mine site to reduce the ore material into particles less than 150 millimeters (mm) (6 inches) in diameter. The crushed ore is then transported to a mill site for additional crushing, grinding, classification, and concentration.

Additional milling uses a cone crusher, usually followed by grinding in rod and ball mills. Grinding is a wet operation in which water and initial flotation reagents are added to form a slurry. Alternatively, the ore may be fed into an autogenous mill (where ore acts as a grinding medium) or a semi-autogenous mill (where the ore is supplemented with large steel balls).

Between each grinding unit operation, hydrocyclones are used to classify coarse and fine particles. Coarse particles are returned to the mill for further size reduction. The resulting size of the classified ore is usually about 65-mesh (.208 mm). Chemical reagents that will be used during flotation separation activities may be added to the ore during milling activities (U.S. DOI, Bureau of Mines, 1985a; 1990a). Mill production capacities can be as high as 7,000 to 9,000 tons per day. Mills located in the eastern United States grind ore that is predominantly composed of zinc, with smaller quantities of lead and other minerals. Mills in the midwest, including some in Missouri, grind ore that is predominantly lead with smaller amounts of zinc and other minerals. Western mills produce various combinations of lead and zinc (White and Clifford, 1977; Chandler, 1970).

1.4.2.2 Flotation

Flotation is a technique by which particles of one mineral or group of minerals are made to adhere preferentially to air bubbles in the presence of a chemical reagent (U.S. EPA, Office of Water, 1982). This is achieved by using chemical reagents that preferentially react with the desired mineral. Flotation is the most commonly used method to concentrate lead-zinc minerals. The effectiveness of the technique, however, is dependent on four factors related to the nature of the ore body: the degree

of oxidation of the ore, the abundance of iron sulfides, the presence of copper minerals, and the basic or acidic nature of the gangue (Weiss, 1985).

In addition to those factors related to the mineralogy of the ore, other factors are also important to the success of flotation activities. These factors include uniformity of particle size, use of reagents compatible with the mineral, and water conditions that will not interfere with the attachment of the reagents to the mineral or air bubbles (U.S. EPA, Office of Water, 1982).

Ore may be treated with conditioners and regulators during or after milling to modify the pH of the ore pulp for flotation (U.S. EPA, Office of Water, 1982). Depending on the ore characteristics, these conditioners or regulators may include lime, soda ash (sodium carbonate), caustic soda (sodium hydroxide), or sulfuric acid. The conditioned ore is then slurried in a solution of fresh or salt water with chemical reagents of four main groups. Reagents typical of each group are presented in Table 1-4. Below is a description of the function of each group (U.S. EPA, Office of Water, 1982; Weiss, 1985; U.S. DOI, Bureau of Mines, 1985a):

- Collectors (promoters) - Cause adherence between solid particles and air bubbles in a flotation cell.
- Frothers - Stabilize air bubbles by reducing surface tension, thus allowing collection of valuable material by skimming from the top of the cell.
- Activators - Promote flotation in the presence of a collecting agent when added to mineral pulp.
- Depressants - React with particle surfaces in the flotation cell to keep materials from remaining in the froth. Instead, materials fall to the bottom as tails.

For example, flotation of galena in the presence of sphalerite is possible by adding sodium cyanide (NaCN) and xanthate. Sodium cyanide depresses the sphalerite but not galena (see Table 1-4). After the galena has been collected from the froth, sphalerite can be floated by adding copper sulfate (CuSO₄) and xanthate (Considine, 1975).

Several factors are important when conditioning the ore for flotation with chemical reagents. These include thorough mixing and dispersal of reagents through the pulp; repeated contact between the reagents and all the relevant ore particles; and time for the development of contacts with the reagents and ore particles to produce the desired reactions. Reagents may be added in a number of forms, including solid, immiscible liquid, emulsion, and solution in water. The concentration of reagents must be closely controlled during conditioning; adding more reagent than is required may retard the reaction and reduce efficiency (Fuerstenau, 1976).

Table 1-4. Commonly Used Reagents in Lead and Zinc Flotation

Type of Reagent	Lead Flotation	Zinc Flotation
Promoter	Aerofloats Aerophine Minrec A Xanthates	Xanthates Aerofloats Sodium Aerofloat
Frother	Dow Froth Methyl Isobutyl Carbinol Pine Oil	Dow Froth Flotal B Methyl Isobutyl Carbinol Pine Oil
Activator	Alkaline Sulfides Phosphate	Copper Sulfate
Depressant	Cyanide (Sodium or Calcium) Sodium Bisulfate Dichromate Zinc Hydrosulfate Zinc Sulfate	Sulfur Dioxide Sodium Hydrogen Sulfide Zinc Sulfate Sodium Cyanide

Source: U.S. EPA, Office of Water, 1982; Fuerstenau, 1976

Typical flotation conditioning includes the following steps (Fuerstenau, 1976):

- Addition of modifiers, conditioners, and regulators to disperse slime coatings of pulp molecules and to adjust pulp pH
- Resurfacing and the addition of necessary depressants and activators
- Final pH adjustment
- Addition of and coating of collectors on pulp molecules
- Addition of frother
- Addition of small air bubbles to flotation cells by an air blower or by the action of a submerged rotor or impeller

Figure 1-1 presents a cross section of a typical flotation cell (Envirotech, 1974). The current trend is toward the development of larger flotation cells that are more energy efficient. Pulp, a suspension containing milled ore and flotation reagents, is fed to flotation cells. Typically, 10 to 14 cells are arranged in a series from roughers to scavengers. Roughers are used to make a coarse separation of values from the gangue. Scavengers recover smaller quantities of the remaining values from the pulp (Fuerstenau, 1976). Froth sent from the scavengers and roughers go to cleaner cells where residual wastes are removed and a concentrate is produced.

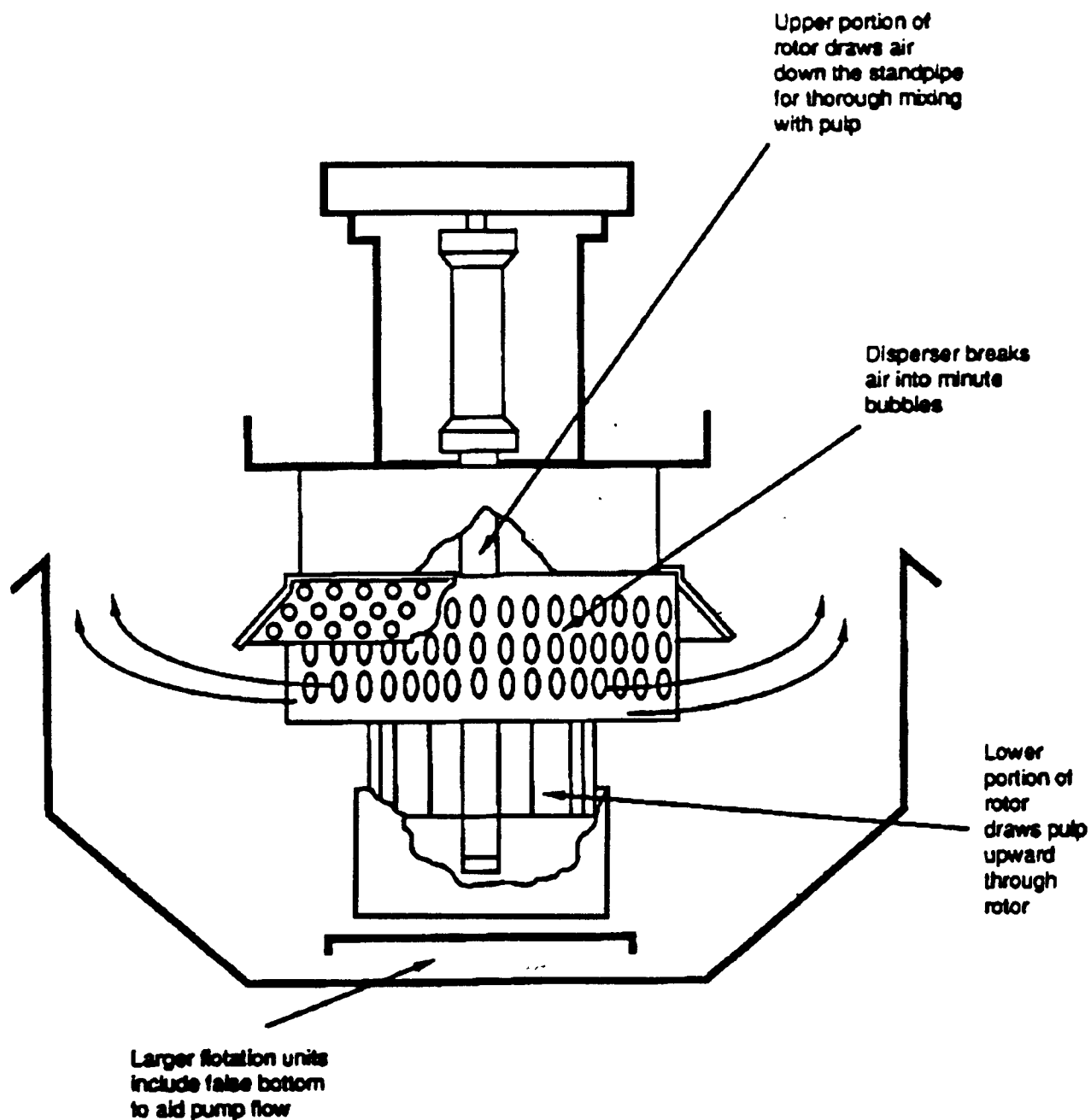


Figure 1-1. Cross-Section Of a Typical Flotation Cell

Source: Envirotech, 1974

The height of the flotation column is determined by the position of the overflow weir. A cell may function as a rougher, a scavenger, or a cleaner depending on its location in the circuit. In rougher cells, the flotation column is kept tall with a thick froth created by the reaction of flotation reagents in contact with the mineral as air is pumped into the bottom of the cell (Fuerstenau, 1976).

Several separate flotation steps may be necessary to beneficiate a polymetallic ore. Most sulfide ores contain varying amounts of minerals such as lead, zinc, copper, and silver; thus, multiple floats are needed to concentrate individual metal values (U.S. DOI, Bureau of Mines, 1985a; Weiss, 1985). The tailings (residual material) from one mineral float are often used as feed for a subsequent float to concentrate another mineral. A typical example includes the following steps, which are also illustrated in Figure 1-2 (Fuerstenau, 1976):

- Bulk flotation of lead-copper minerals and depression of zinc and iron minerals
- Flotation of a copper concentrate and rejection of a lead (sink) concentrate; lead is recovered in a subsequent series of steps
- Activation and flotation of the sphalerite from iron and gangue minerals
- Flotation of pyrite, if recovery is desired
- Flotation of barite concentrate.

A discussion of the specific flotation activities for polymetallic ores employed by several concentration operations, as well as a summary of the grades and recovery rates of several concentrators, is presented in Appendix 1-A.

The froth recovered in the cleaning cells is transferred to thickeners, where the concentrate is then thickened by settling (see Figure 1-3). The thickener underflow (the concentrate) is pumped, dewatered by passage through a filter press and then dried. The liquid overflow from the thickener contains waste water, flotation reagents, and dissolved and suspended mineral products. This solution may be recycled or sent to a tailings pond (Fuerstenau, 1976).

Wastes from the rougher, scavenger, and cleaning cells are collected and directed to a tailings thickener. Overflow from this unit (wastewater containing high solids and some wasted reagent) is often recycled back to the flotation cells. Thickener underflow (tailings) contain remaining gangue, unrecovered lead-zinc material, chemical reagents, and waste water. This underflow is pumped as a slurry to a tailings pond. The solid content of the slurry varies with each operation, ranging from 30 to 60 percent. At the tailings pond solids are settled out of the solution and the clarified waste water may be recycled to the mill. Coarse tailings are sometimes sold as mortar sand and agricultural lime. Tailings are also used as fill for underground mine workings (White and Clifford, 1977).

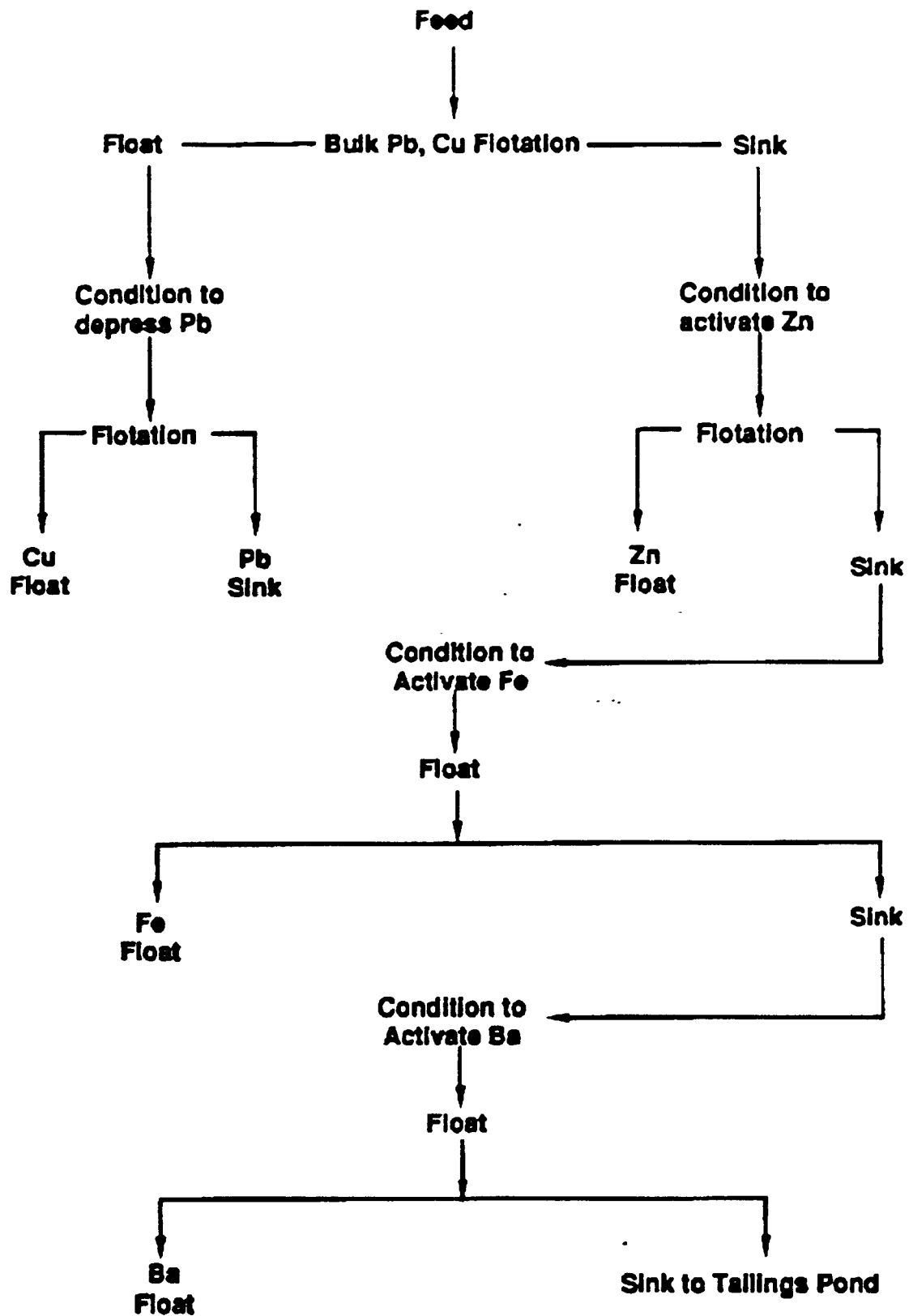


Figure 1-2. Typical Flow Sheet for Polymetallic Ore Flotation

Source: Fuerstenau, 1976

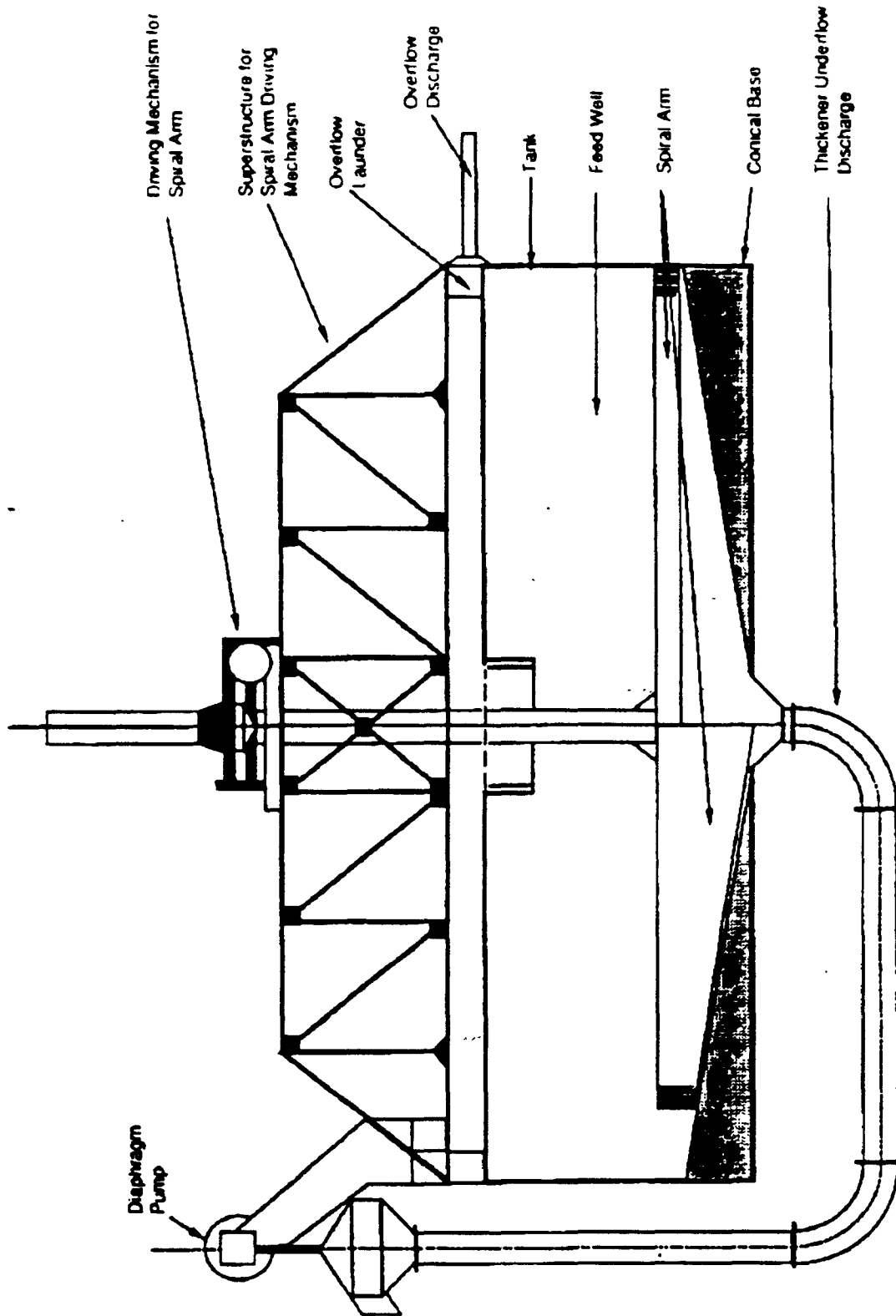


Figure 1-3. Cross Section of a Typical Thickener

Source: Fuerstenau, 1976

1.4.2.3 Roasting and Sintering of Concentrates

Concentrates of lead and zinc minerals that are to be processed by pyrometallurgical methods such as smelting and refining may require sintering, depending on the processing methods used. Sintering involves the partial fusion of ore concentrates into an agglomerated material suitable for processing operations. The sinter material is typically a crushed and graded structure of porous, cellular solids (Weiss, 1985).

Sintering operations consist of several steps, including blending, sintering, cooling, and sizing. Raw materials, such as ore concentrates, ore screening, fluxes, plant recycle dusts, filter cake, and coke breeze are blended with small amounts of moisture in pug mills, balling drums, or balling pans. The concentrate feed is then fired (sintered) and cooled. During cooling, the sinter is crushed and is typically less than six inches in diameter. This product will be graded and further crushed in some operations to produce a smaller sinter product (Weiss, 1985).

Of the five primary lead processing facilities in the United States, four sinter the concentrate prior to processing. They are the Doe Run facility in Boss, Missouri; the Doe Run facility in Herculaneum, Missouri; the ASARCO facility in East Helena, Montana; and the ASARCO facility in Glover, Missouri. The ASARCO facility in Omaha, Nebraska, is a refinery, not a smelter, and thus does not have a sintering operation (U.S. EPA, Office of Solid Waste, 1990).

The sinter plant at the Doe Run smelter and refinery in Herculaneum, Missouri, first became operational in the early 1900s and was last modernized in 1967. Inputs to this operation include lead concentrate (204,000 st), sand (6,100 st), hematite (99,200 st), coke breeze (7,500 st), baghouse fume (29,400 st), dewatered sludge and fines (22,000 st), and slag (176,100 st). The maximum practical operating capacity in 1988 was 1,975 st per day. The plant was in operation 323 days in 1988. The principal product was 478,660 st of finished sinter. Residues generated included primary lead slag, dust and primary lead process water (U.S. EPA, Office of Solid Waste, 1990).

The sinter plant at the ASARCO smelter in East Helena, Montana, was built in 1923 and was last modernized in 1977. The inputs for this operation are ore concentrates, recycled dust, and sinter wastewater treatment plant sludge. The wastes generated by the sinter plant include process water and dust (U.S. EPA, Office of Solid Waste, 1990).

The ASARCO smelter and refinery in Glover, Missouri, operated a sinter plant that was built in 1968 and was last modernized in 1977. The inputs to the operation include ore concentrates, 1/3 of the slag generated from the smelter, sludge from the waste water treatment plant, and waste water that is recycled to the sinter plant. The primary product from the sinter operation is sinter. Wastes, including process water and dust, are also generated in the process (U.S. EPA, Office of Solid Waste, 1990).

The Big River zinc facility in Sauget, Illinois; the Jersey Miniere zinc facility in Clarksville, Indiana; and the Zinc Corporation of America facility in Bartlesville, Oklahoma, are all electrolytic zinc operations that have roasting operations with zinc concentrate as an input, but they are not smelting operations. The Zinc Corporation of America pyrometallurgical facility in Monaca, Pennsylvania, however, does have a sintering operation. The inputs to this operation are roasted ore, sinter plant baghouse dust, and zinc lean fines (U.S. EPA, Office of Solid Waste, 1990).

1.5 EXTRACTION AND BENEFICIATION WASTES ASSOCIATED WITH LEAD-ZINC MINES

Wastes generated by lead-zinc operations include mine water, waste rock, tailings, and refuse. Many of these wastes may be disposed of onsite or offsite, while others may be used or recycled during the active life of the operation. Waste constituents may include base metals, sulfides, or other elements found in the ore, and any additives used in beneficiation operations. The primary waste generated by mineral extraction in underground mines is mine development rock, which is typically used in onsite construction for road or other purposes. Surface mines usually generate large volumes of overburden and waste rock that are usually disposed of in waste rock dumps.

In general, most wastes from beneficiation of lead-zinc ores are disposed of in tailings impoundments from which water is likely to be reclaimed during the mine's life. Some materials may be either used on site or disposed of, depending on the operating conditions of a facility at a specific time. For example, mine water pumped from the mine to de-water active work areas can be used in beneficiation operations, often with excess mine water being disposed of as a waste by discharge through a NPDES permit. Wastes that can be either used during operation, and/or disposed of depending on site-specific conditions, are described in this section.

In addition to wastes generated as part of extraction and beneficiation, facilities also store and use a variety of chemicals required by the mine and mill operations. A list of chemicals used at lead-zinc mines, compiled from data collected by the National Institute for Occupational Safety and Health (NIOSH), is provided below (National Institute for Occupational Safety and Health, 1990).

Acetylene	Sodium Cyanide	Methane, Chlorodifluoro-
Calcium Oxide	Sulfur Dioxide	Sodium Aerofloat
Hexone	Sulfuric Acid	Sulfuric Acid Copper (2+)
Hydrogen Chloride	Diesel Fuel No. 1	Salt (1:1)
Methyl Chloroform	Diesel Fuel No. 2	Zinc Solution
Methyl Isobutyl Carbinol	Chromic Acid, Disodium Salt	Zinc Sulfate
Nitric Acid	Copper Solution	
Propane	Kerosene	

1.5.1 Extraction and Beneficiation Wastes

1.5.1.1 Overburden and Mine Development Rock

Waste generated as a result of lead-zinc mining include overburden and mine development rock, collectively referred to as waste rock. As noted previously, the materials can be used onsite or placed in waste rock dumps. The quantity and composition of waste rock generated at lead-zinc mines varies greatly between sites. These wastes will contain minerals associated with the ore body and host rock.

Typical minerals associated with sulfide ores are chalcopyrite, pyrite, calcite, and dolomite (Weiss, 1985).

At the Doe Run facility in Viburnum, Missouri, mine development rock (called "shaft rock" by Doe Run) is used as a construction material around the mine. Other mine development rock from underground operations is simply stored in underground openings (Carter, 1991b).

1.5.1.2 Mine Water

Mine water is generated when water collects in mine workings, both surface and underground, as a result of inflow from rain or surface water and from ground-water seepage. During the active life of the mine, water is pumped out of the mine as necessary to keep the mine dry and allow access to the ore body for extraction. As mentioned above, this water may be used in beneficiation operations or stored on-site and discharged as a waste through an NPDES permit.

The quantity and chemical composition of mine water generated at mines varies from site to site. The chemistry of mine water is dependent on the geochemistry of the ore body and the surrounding area. Mine water may also contain small quantities of oil and grease from extraction machinery and nitrates (NO₃) from blasting activities. Chemical characteristics of mine water from several lead-zinc mines are shown in Table 1-5 (U.S. DOI, Bureau of Mines, 1984; U.S. EPA, Office of Solid Waste, 1985). This table shows the chemical composition of such waters. The range of concentrations in mine water (mg/l) for lead was .1-1.9, zinc .12-.46, chromium .02-.36, sulfate 295-1,825, and pH 7.9-8.8.

After the mine is closed and pumping stops, the potential exists for water exposed to sulfur-bearing minerals in an oxidizing environment, such as open pits or underground workings, to acidify. This may lead to the mobilization of metals and other constituents in the remaining ore body exposed by mining and to the contamination of surface and/or ground water.

Actions taken by mine operators to control water during the active life of the mine include pumping from sumps within the mine or from interceptor wells, which withdraw ground water and create a cone of depression in the water table, thus dewatering the mine. Surface water is often controlled using diversion and other engineering techniques to prevent water from flowing into the mine. (U.S. DOI, Bureau of Mines, 1984; U.S. EPA, Office of Solid Waste, 1985).

The Magmont facility in Missouri anticipated that 3,000 gallons per minute (gpm) of water would eventually be pumped from the mine. The facility has installed a permanent underground pumping station, including settling sumps, to address this problem. It is noted that the sumps settle between 20 and 30 tons of sludge from mine water per week during operations. The settled mine pump-out water is sent to the mill to be used as process water or channeled directly to tailings ponds, along with the settled sludge (Schwandt, 1970). In the Viburnum Trend, mine water from the underground mines is pumped at a rate between 300 and 7,000 gpm for each mine.

**Table 1-5. Range of Constituents of Waste Water and Raw Mine Waters Loads
From Five Selected Lead-Zinc Mines**

Parameter	Range of Raw Waste Load					
	Range of Concentration in wastewater, mg/l		Per unit ore milled, g/t		Per unit concentrated produced, g/t	
	lower limit	upper limit	lower limit	upper limit	lower limit	upper limit
Alkalinity	26	609	410	1,600	1,450	10,200
Hardness	310	1,760	460	4,700	2,290	32,500
Total suspended solids (TSS)	2	108	7	285	30	2,000
Total dissolved solids (TDS)	670	2,834	940	8,500	4,800	50,900
Chemical oxygen demand (COD)	71.4	1,535	6	4,800	30	50,000
Total oxygen content (TOC)	11	35	6.35	130	30	580
Oil and grease	0	8	5	21	30	130
MBAS surfactants	.18	3.7	.236	13	2.05	60.7
P	.42	.150	.108	.876	.54	2.54
Ammonia	.05	14	.064	26.4	.32	185
Hg	.0001	.1	.00013	.0026	.00168	.130
Pb	.1	1.9	.127	6.9	.900	32.2
Zn	.12	.46	.089	17.2	.62	86.0
Cu	.02	.36	.026	.158	.18	1.96
Cd	.005	.011	.008	0.18	.18	8.85
Cr	.02	.67	.026	1.77	.45	1.39
Mg	.02	.08	.026	.290	.012	10.0
Fe	.05	.53	.064	1.16	.091	.198
Cyanide	.01	.03	.013	.109	1,260	509
Sulfate	295	1,825	130	4,800	210	33,700
Chloride	21	395	20	870	230	4,070
Fluoride	.13	.26	.370	.944	-	5.45
pH*	7.9	8.8	-	-	-	-

*Value in standard units

Source: U.S. DOI, Bureau of Mines, 1984

After closure, both surface and underground mines fill with water as ground water rises to pre-mining levels. As with active mines, the quantity and chemical composition of mine water varies from mine to mine and is dependent on the geochemistry of the area.

1.5.1.3 Flotation Wastes

After the removal of values in the flotation process, the flotation system discharges tailings composed of liquids and solids. Between 1/4 and 1/2 of the tailings generated are made up of solids, mostly gangue material and small quantities of unrecovered lead-zinc minerals. The liquid component of the flotation waste is usually water and dissolved solids, along with any remaining reagents not consumed in the flotation process. These reagents may include cyanide, which is used as a sphalerite depressant during galena flotation. Most operations send tailings to impoundments where solids settle out of the suspension¹. The characteristics of tailings from the flotation process vary greatly, depending on the ore, reagents, and processes used. As shown in Table 1-5, lead, zinc, chromium, iron, and sulfate were all found in the waste water of the selected facilities (U.S. DOI, Bureau of Mines, 1984).

In 1980, the St. Joe Minerals Corporation tailings pond at Viburnum received mill wastes transported in a slurry of about 35 percent solid material. In July 1982, water from the pond had a dissolved lead concentration of less than 84 micrograms per liter ($\mu\text{g/l}$), a dissolved zinc concentration of 620 $\mu\text{g/l}$, a dissolved arsenic concentration of 43 $\mu\text{g/l}$, dissolved cadmium and copper concentrations of less than 2 $\mu\text{g/l}$, and a dissolved selenium concentration of 81 $\mu\text{g/l}$. During 1980, the fresh tailings had a lead content of 736 micrograms per gram ($\mu\text{g/g}$), a zinc content of 260 $\mu\text{g/g}$, an arsenic content of 34 $\mu\text{g/g}$, a cadmium content of less than 10 $\mu\text{g/g}$, a copper content of 449 $\mu\text{g/g}$, and a selenium content of 6.1 $\mu\text{g/g}$. Settled solids had a lead content of 358 $\mu\text{g/g}$, a zinc content of 222 $\mu\text{g/g}$, an arsenic content of 35 $\mu\text{g/g}$, and a selenium content of 1 $\mu\text{g/g}$ (U.S. EPA, Region VII, 1983).

1.5.2 Waste Management

Wastes generated as a result of extraction and beneficiation of lead and zinc minerals are managed (treated, stored, or disposed) in discrete units. For the purposes of this report, these units are divided into three groups: waste rock piles, mine pits and underground structures, and tailings impoundments.

1.5.2.1 Waste Rock Piles

Waste rock (overburden and mine development rock) removed from the mine is stored or disposed of in unlined piles onsite. These piles may be referred to as mine rock dumps or waste rock dumps. Constituents of concern in runoff and leachate from waste rock piles may include heavy metals.

¹EPA has prepared a separate report on tailings disposal in impoundments.

These piles also could generate acid drainage if sulfide minerals, oxygen, and moisture are present in sufficient concentrations without adequate neutralization potential or other controls.

1.5.2.2 Mine Pits and Underground Workings

In addition to wastes generated during active operations, when the mines close or stop operation, pits and underground workings may be allowed to fill with water, since there is no longer a need for dewatering. This accumulating water, which may become mine drainage, can acidify through aeration and contact with sulfide minerals and become contaminated with heavy metals.

At pits where quartz minerals are associated with lead-zinc deposits, silica dust exposure may be a problem both during mine operations and following closure. Asbestos, which may be present in pits where limestone and dolomite ores are mined, may also be a concern (U.S. Department of Health and Human Services, 1982).

1.5.2.3 Tailings Impoundments

Tailings are the discarded material resulting from the concentration of ore through various beneficiation operations. This material has minimal value at present but is produced in extremely large quantities. Tailings are characterized by fine particle sizes and varying mineralogical and chemical compositions. Tailings typically take the form of a slurry; the waste slurries from milling, gravity concentration, and flotation contain approximately 65 percent water and 35 percent solids (Carter, 1991a).

The disposal of tailings requires a permanent site with adequate capacity for the life of the mine. The method of tailings disposal is largely controlled by the water content of the tailings. Literature consulted for this report suggests that only impoundments are used in the lead and zinc industries. However, historic beneficiation methods using vibrating tables to concentrate values produced "middlings" or "chat," that was disposed of in tailings piles. This technique is not used in modern lead-zinc mill operations.

Tailings impoundments are created as disposal sites for wet and thickened tailings that leave the mill in the form of slurries. After settling in the impoundment, the aqueous component is typically decanted and pumped back to the mill. Two general classes of structures may be used to construct a tailings impoundment: water-retention dams and raised embankments. Water retention dams involve the construction of a dam with a low permeability core while raised embankments are constructed of waste rock and tailings, with permeability usually controlled by tailings gradation. Both the water retention and raised embankment methods rely on natural topography to assist in the impoundment of tailings and tailings water. The height of a raised embankment may be increased to expand storage. The choice of impounding structure is influenced by the characteristics of the mill tailings, as well as the site. Evaporation and seepage may occur with both types of impoundments.

The size of tailings impoundments varies among operations. For example, the impoundment at the Magmont facility in Missouri consists of an 85-foot high by 1,000-foot long compacted earth-filled dam and an 80-acre pond (Schwandt, 1970). The Doe Run Company Fletcher Project, also in Missouri, is currently planning to expand its tailings pond capacity from its current 140 acres to 239 acres. At capacity, the pond contents will be 4 percent liquid and 96 percent solids. The planned expansion will accommodate the wastes generated from the remaining ore reserves of approximately 20 million tons (Doe Run Company, 1990).

1.5.2.4 Leachate

Leachate or runoff generated by exposing mine waste to precipitation may escape into the environment. Such leachate is not mine waste, but may be subject to regulation under the Clean Water Act (CWA) or the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

1.6 ENVIRONMENTAL EFFECTS

Nearly any portion of waste management units at active mines may be a potential source of environmental contamination. Waste rock piles and tailings impoundments are of particular concern since these are the areas in which toxic contaminants most commonly are found. Contaminants associated with these areas may include heavy metals, reagents, and acid rock drainage that may degrade ground water, surface water, soil, and air quality during mine operation and after mine closure. A discussion of the potential environmental effects associated with lead-zinc mining is presented in the following sections. Specific examples from industry are included in this section, as appropriate. Actual release incidents occurring at lead-zinc mine sites are described in the Damage Case Section of this report.

This section does not purport to be a comprehensive examination of environmental damages that can occur or that actually occur at mining operations. Rather, it is a brief overview of some of the potential problems that can occur under certain conditions. The extent and magnitude of contamination depends on highly variable site-specific factors that require a flexible approach to mitigation. EPA is aware that many of the potential problems can be, and generally are, substantially mitigated or avoided by proper engineering practices, environmental controls, and regulatory requirements.

1.6.1 Ground Water/Surface Water

Sources of ground and surface water contamination include runoff, leachate, and seepage from tailings impoundments, mine pits and workings (after mine closure), as well as waste rock piles.

For lead and zinc recovered from sulfur-bearing ores, acid generation due to oxidation of sulfides in the ore body, host rock, and waste material may be of special concern. Acidified water increases the potential for leaching heavy metals from these sources and facilitates their transport. Factors that influence the acid generation potential include the sulfide content, the buffering capacity of the ore and/or tailings, exposure of mineral surfaces in an oxidizing environment, moisture, and the hydrogeology of the area. Some bacteria, such as Thiobacillus ferrooxidans, are catalysts for oxidation of sulfur-bearing minerals leading to acid generation. These bacteria pose a particular problem in waste rock piles and tailings impoundments.

As water acidifies, the potential for leaching and mobilization of metals and other contaminants increases. The suite of elements and minerals that may be associated with lead-zinc deposits includes mercury, tellurium, cobalt, thallium, pyrite, and pyrrhotite. Lowering of pH affects the solubility of these constituents making them available for transport in both surface and ground water. Whether these contaminants will migrate depends on the geochemistry in the vicinity. It should be noted that the ore host rock in most U.S. lead mines is a dolomitic limestone. However, not all reactions are

dependent on low pH. For example, high concentrations of arsenic have been found to be mobile at a pH of 10 (U.S. EPA, Office of Solid Waste, 1990).

EPA and PEDCO conducted a cooperative study in 1983 concerning the St. Joe Minerals Corporation's Viburnum Mine tailings pond. Results showed that, on average, calcium, sodium, magnesium, TDS, sulfate, nitrate, potassium, and chloride were higher downstream of the pond than upstream. It was not clear, however, that this was due to tailings disposal activities (U.S. EPA, Region VII, 1983).

Surface and underground mines must be dewatered to allow extraction of ore. This can be accomplished in one of two ways: pumping from ground water wells to lower the water table or pumping directly from the mine workings. After a mine is abandoned, pumping is usually stopped, allowing the pit or workings to fill with water. Over time, this may lead to uncontrolled releases of mine water. The mine water may be acidic and contain metals, as well as dissolved and suspended solids.

1.6.2 Soil

Environmental impacts to soils as a result of mining activities are most commonly associated with erosion and contamination. Erosion may be caused by land disturbances and removal of vegetation related to mining activities. Under these conditions, precipitation events such as snowmelt may lead to erosion of soils.

Contamination of soils may occur from discharge, runoff, leachate, and seepage from tailings impoundments, pits and underground workings, as well as waste rock piles. In addition, deposition of wind-blown particulates from dry tailings impoundments may also be a source of soil contamination. Other sources of soils contamination include spills of fuel, flotation reagents, cleaning solutions, as well as other chemicals used or stored at the site.

Soils, if they become contaminated, contain substances found in the waste materials, including those materials discussed in the Ground Water/Surface Water Section above. Contaminated soils may further act as a source of contamination to ground water, surface water, and in some instances as a source of air pollution due to re-entrainment and/or subsequent deposition of particulates. In some instances, direct human contact has occurred when tailings have been used in sandboxes, as soil amendments, and as construction fill material, although these are generally historic practices.

1.6.3 Air

The primary source of air contamination at mine sites is fugitive dust from the dry surfaces of tailings impoundments, as well as waste rock piles, if they are exposed to the environment (Cornell, 1991). Often, tailings impoundments are not completely covered by water, thus dry tailings are commonly

available for wind-blown transport (as discussed above). Deposition of wind-blown tailings provides exposure routes for contamination of ground water, surface water, and soil. Potential contaminants include those discussed in the Ground Water/Surface Water Section.

1.6.4 Damage Cases

Damages resulting from waste management from mining lead and zinc metals and associated minerals have been documented. Superfund, the Clean Water Act, and other EPA investigations have verified contamination to ground water, surface water, air, and soil media. Examples include the following:

- Lead, zinc, and other contaminants in ground water proximal to mine sites have contaminated drinking water resources.
- Acid mine drainage and associated contaminants flowing to surface water have given rise to pollution of the water resources and sediments.
- Wind-blown tailings have posed health risks to humans through their inhalation of gas and dust containing pollutants.
- Deposition of sulfur compounds and other contaminants, such as dust from wind-blown tailings, in soils have provided human exposure pathways.
- Misuse and mismanagement of wastes, including construction of housing directly on wastes and use of tailings in gardens, have provided human exposure pathways.

1.6.4.1 National Priorities List Sites

EPA reviewed sites on the NPL and found that lead-zinc extraction and beneficiation was conducted at the following sites: Iron Mountain in Redding, California; California Gulch in Leadville, Eagle Mountain in Gilman, and Smuggler Mountain in Pitkin County, all in Colorado; Bunker Hill in Kellogg, Idaho; Cherokee County, Kansas; Oronogo-Duenweg Mining Belt in Missouri; Tar Creek, on the border between Oklahoma and Kansas; all parts of the Tri-State Mining District in Kansas, Oklahoma, and Missouri; and Sharon Steel/Midvale Tailings in Midvale, Utah. Many of these sites represent an accumulation of wastes over an extended period of operations. For example, Oronogo-Duenweg operated for more than 100 years. Mining of the Bunker Hill site ceased in 1991, also over 100 years after mining began. Appendix 1-B provides a general site description and a summary of the environmental effects associated with these sites.

1.6.4.2 Clean Water Act Section 304(l) Sites

Section 304(l) of the Water Quality Act of 1987 requires States to identify water bodies not meeting applicable water quality criteria, to identify point source dischargers to these water bodies, and to develop and require implementation of Individual Control Strategies (ICSs) for those point source dischargers that contribute significantly to exceedance of the water quality criteria. The 304(l) program has identified two lead-zinc sites as sources of contamination to surface waters.

The Black Cloud Mine and Mill, a Res-ASARCO Joint Venture, is an active lead-zinc operation near Leadville, Colorado. All mine and mill waste waters are directed to a tailings pond. In addition, all runoff from process areas drains to the tailings pond, which discharges to Iowa Gulch (a tributary of the Arkansas River). The discharge from the tailings pond has been shown to be toxic to aquatic life. The facility has consistently exceeded the discharge limitations for TSS, cyanide, zinc, and manganese.

The Rico Mine Development Corporation operates a treatment system for mine drainage from the inactive Rico Mine, which produced lead, zinc, and silver. The discharge from the mine has been identified as contributing to toxicity in Silver Creek (a tributary of the Delores River). The toxicity in the discharge results from high concentrations of metals that exceed applicable water quality-based standards.

1.6.4.3 Other Reported Damage Cases

EPA Study of Missouri Damages

In 1984, EPA summarized damage from the disposal of mining wastes. For the State of Missouri, 14 sites related to lead-zinc mining were identified. Of these sites, six were active mines and eight were inactive. The results of this study are summarized in Table 1-6 (SCS Engineers, 1984) (note that individual mine site names were withheld by the source). Typical problems include surface water quality degradation and pollution due to catastrophic and intermittent releases from tailings or settling ponds. Typical pollutants included lead, zinc, cadmium, copper, organics, and sediment.

Red Dog Mine, Alaska

The partnership of Cominco Alaska, Inc., and the Kotzebue-based NANA Regional Corporation owns Red Dog Mine, which is one of the largest lead-zinc operations in the world. Cominco began development of Red Dog Creek in 1982 and Red Dog Mine began major construction in 1989. The Red Dog ore deposit in the DeLong Mountains contains large amounts of zinc and lead, as well as aluminum, copper, iron, cadmium, silver, and nickel. Leaching of metals from the ore-rich DeLong Mountains into Red Dog Creek has been documented for years, but it has increased dramatically since Red Dog Mine reached full production in the summer of 1990. Red Dog Creek contains no fish, partly because of high metal concentrations. It does, however, empty into the Ikalukrok Creek, which in turn empties into the Wulik River. This area is one of the richest fisheries in northwestern Alaska. Ikalukrok Creek is a wintering ground for Dolly Varden (Arctic char), and Wulik River is a major habitat for Dolly Varden and spawning salmon. The Wulik River also flows to the small Inupiat Eskimo community of Kivalina, about 60 miles downstream from the mine. Villagers there catch fish and draw drinking water from the river.

Table 1-6. Missouri Mining Waste Damage Cases

Background					Problems					Damage			Mitigation	
Mining Segment	Facility Status	Waste Source	Waste Type	Mgmt. Practice	Date	Release Type	Release Period	Cause	Pollutants	Receptor	Effect	Magnitude	Action	Type
Pb, Zn	Active	Mine	Tails; mine water	Ponds; meanders		Discharge	Intermittent	Discharge (Deliberate)	Sedmt. metals, organics	SW; benthos	WQ degrad.	3 ml creek red. benthic coms	Y	Meander system, 2nd settling pond
Pb, Zn	Inactive	Mine	NS	NS		Sedmt.			Sedmt.	SW; benthos	WQ degrad.	6 m. degrad in creek, red benthic coms	N	
Pb, Zn, Cu	Inactive	Mine	Tails	Pond	3/1/78	Tails; water	Catastrophic	Dam failure	Sedmt. Cd, Cu, Pb, Zn	SW; soil	WA degrad.; turbidity 5ml in river	Killed crops; red lead value	Y	Dam repaired
Pb, Zn, Cu	Act	Mine; mill	Tails	Ponds	3/29/77	Tails	Catastrophic	Dam breach; Heavy rains	Sedmt. Pb, Zn	Sw	WQ degrad.	Heavy metals accum. in lake	Y	Stab dam
Pb, Zn, Cu	Inactive	Mine	Tails	Pile; pond	3/25/78	Sedmt.	Intermittent	Rains	Sedmt., Pb, Zn, Cd, Cu	SW, fish	WA degrad.	Uptake PL by plants, fish	N	
Pb, Zn, Cu	Inactive	Mine	Tails	Pile	1977	Tails; washout	Catastrophic	Heavy rains; wind erosion	Sedmt., Pb, Zn, Cd, Cu, Be	SW	WA degrad; severe pile erosion	Uptake PL by plants, fish	N	
Pb, Zn, Cu	Active	Mine	Tails; mill reagent wastes	Pond		Runoff; discharge	Intermittent	Heavy rains	Pb, Zn, Cu, Cd, Mg, sedmt	SW	WA degrad.	Potential bioacc.	N	
Pb, Zn, Cu, Ag	Active	Mine; mill	Tails; mill reagent wastes	Ponds		Discharge; seepage	Intermittent	Mill trmt. pond thru end pipe	Sedmt., metals, organics	SW; benthos	WA degrad.	Red. benthic Org	Y	Recycling to control excess discharge
Pb, Zn, Cu, Ag	Active	Mine; mill	Tails; mine water	Pond		Runoff	Intermittent	Heavy rains	As, Hg, Cu, Pb, Cd, Sedmt	SW; benthos	WQ degrad.	Limited	Y	Stab or dam, water recycle
Pb, Zn, Cu, Ag	Inactive	Mine; mill	Tails, mine water	Ponds		Releases	Intermittent	Heavy rains	Sedmt. metals	SW	Potential WQ degradation	Effect on benthic coms not known	N	
Pb, Zn, Cu, Ag	Inactive	Mine	Tails	Pile; basin		Seepage	Intermittent	Small lakes formed on pile	Sedmt. Pb, Zn, Cu, Cd	SW	WQ degrad.	Uptake PL by plants, fish	N	
Pb, Zn, Cu, Ag	Inactive	Mine	Tails	Pile; pond		Sedmt.	Seasonal	Heavy rains	Sedmt., Pb, Zn, Cu, Cd	SW	WQ degrad.	Unknown	Y	New pond (1971)
Pb, Zn, Cu, Ag	Inactive	Mine	Tails	Pile		Tails	Seasonal	Erosion; heavy rains	Sedmt., Pb, Zn,	SW	WQ degrad.	Uptake PL by fish, plants	N	
	Active	Mine	Tails;	Ponds; lagoons	8/1/75	Tails, water runoff	Catastrophic	Dam failure	Cd, Cu	Sw, fish	Severe WQ degrad	Fishkill, damage to invert. coms	Y	Stab & matr. of dam
		Mines	Tails	Ponds		Runoff	Intermittent	Erosion; insufficient pond capacity	Sedmt.	SW; benthos	WQ poll.	10 5 ml creek red. benthic coms.	N	
Fe		Mine	NS	NS		Sedmt.			Sedmt.	SW, benthos	WQ degrad	Red benthic org	N	

Source: SCS Engineers, 1984. NS = Not Specified; SW = Surface Water; WQ = Water Quality.

In the early 1980s, before mining began, the Alaska Department of Environmental Conservation (DEC) records showed natural concentrations of zinc in Red Dog Creek between 7 and 52 parts per million (ppm), with one reading of 273 ppm. Summer 1990 samples from the creek showed consistent zinc measurements above 100 ppm, with an early July measurement of 970 ppm. Since the fall of 1989, Alaska Department of Fish and Game (ADF&G) biologists have identified discoloration in the form of a milky orange plume of precipitate beginning at Red Dog Mine and flowing downstream for about 20 miles. The source of the water is seepage from the saturated zone associated with the ore body exposed by mining. (Although this is not associated with a waste management activity, there is evidence that water related problems can arise from other parts of the mine operation.) This seep water contains high concentrations of zinc and iron. Cominco has agreed to take appropriate actions to reduce the introduction of heavy metals into Red Dog Creek. (Alaska Department of Environmental Conservation, Northern Regional Office vs. Cominco America, Inc., Compliance Order by Consent).

Balaklala, Keystone, and Shasta King Mines; Shasta County, California

The Balaklala, Keystone, and Shasta King Mines are inactive mines that lie within the Shasta/Trinity National Forest, approximately four miles west of Shasta Dam. All three mines are owned by Silver King Mines, Inc., of Salt Lake City, Utah. Copper, zinc, silver, and gold are mined at these sites.

Acid mine drainage flowing from all three underground mines eventually discharges into Shasta Lake by way of West Squaw Creek. Heavy metals and acidic conditions in this flow have resulted in deterioration of aquatic life downstream of the mines in West Squaw Creek, and periodically cause fishkills at the West Squaw Creek/Shasta Lake confluence.

Monitoring data at the Balaklala and Keystone Mines show highly variable flow rates and metals concentrations (see Tables 1-7 and 1-8). Discharges from the Balaklala Mine currently contribute about 30 to 90 percent of the heavy metals in West Squaw Creek. However, some of this pollution is the result of water coming from the Keystone Mine. About 20 to 500 gpm are discharged from the Keystone mine and joins the discharge from the Balaklala Windy Camp mine.

Prior to sealing, the discharge from the Weil portal at the Balaklala Mine had a pH of 2 and metal concentrations of 170 mg/l of copper and 180 mg/l of zinc. Discharges from the Shasta King Mine are thought to account for a maximum of 6.4 percent of the total heavy metals in West Squaw Creek, although it is impossible to sample the discharge during periods of high runoff (Advanced Environmental Consultants, Inc., 1983).

Table 1-7. Balaklala Mine Typical Metal Concentrations of Discharge

Constituent	Concentration
pH	2.6 to 2.9
Copper	10 to 15 mg/l
Zinc	6 to 30 mg/l
Cadmium	0.1 mg/l
Iron	50 to 240 mg/l

Source: Advanced Environmental Consultants, Inc., 1983

Table 1-8. Keystone Mine Typical Metal Concentrations of Discharge

Constituent	Concentration
pH	2.9 to 3.8
Copper	2 to 13 mg/l
Zinc	3 to 21 mg/l
Cadmium	0.02 to 0.12 mg/l
Iron	9 to 140 mg/l

Source: Advanced Environmental Consultants, Inc., 1983.

1.7 CURRENT REGULATORY AND STATUTORY FRAMEWORK

Lead and zinc mining activities must meet the requirements of both Federal and State regulations. Environmental statutes administered by EPA or the states, such as the Clean Water Act (CWA) and the Clean Air Act (CAA), apply to mining sites regardless of the status of the land on which they are located. The extent to which other Federal regulations apply depends on whether a mining operation is located on federally-owned land. Federal regulations exist for operations on lands managed by the U.S. Bureau of Land Management (BLM), the U.S. Forest Service (FS), the U.S. Fish and Wildlife Service (FWS), the National Park Service (NPS), and other land management agencies. In addition, the U.S. Army Corps of Engineers has promulgated rules for construction and mining activities that have the potential to affect wetlands and navigable waters. Finally, operations must comply with a variety of state requirements, some of which may be more stringent than Federal requirements.

Federal water quality regulations establish specific effluent guidelines for point source discharges to surface waters from lead-zinc mining operations. In contrast, air quality standards do not specifically address lead-zinc emissions from mining operations, but do address particulate matter from metallic mineral processing plants and various emissions from lead and zinc smelters. Federal land management agencies have general mining regulations that are not specific to individual (nonfuel) mineral types. Similarly, State regulations do not usually target specific minerals, but regulate nonfuel mining in general.

This section summarizes the existing Federal regulations that may apply to lead-zinc mining operations. It also provides an overview of the operational permitting (including reclamation and waste management) and water quality, air quality, and wetlands protection regulations in two major lead-zinc producing states - Alaska and Missouri. These states were chosen since the vast majority of lead mining takes place in Missouri, while one of the newest zinc mines in the U.S. operates in Alaska.

1.7.1 Environmental Protection Agency Regulations

1.7.1.1 Resource Conservation and Recovery Act

The EPA implements the Resource Conservation and Recovery Act (RCRA) to protect human health and the environment from problems associated with solid and hazardous wastes. Mining wastes are included in the Act's definition of solid waste and in 1978, when EPA proposed regulations for the Subtitle C hazardous waste program, special management standards were proposed for mining wastes. However, in 1980, RCRA was amended to include what is known as the Bevill Amendment (RCRA §3001(b)(3)(A)). The Bevill Amendment provides a conditional exclusion from RCRA Subtitle C hazardous waste requirements for wastes from the extraction, beneficiation, and processing of ores and minerals.

The exemption was conditioned upon EPA's preparation of a report to Congress on the wastes and a subsequent regulatory determination as to whether regulation under Subtitle C was warranted. EPA met its statutory obligation with regard to extraction and beneficiation wastes with the 1985 *Report to Congress: Wastes from the Extraction and Beneficiation of Metallic Ores, Phosphate Rock, Asbestos, Overburden from Uranium Mining and Oil Shale*. In the subsequent regulatory determination (51 FR 24496; July 3, 1986), EPA indicated that extraction and beneficiation wastes (including lead and zinc mining and milling wastes) should not be regulated as hazardous but should be controlled under Subtitle D.

EPA subsequently studied processing (i.e., smelting and refining) wastes and in 1990 submitted its *Report to Congress on Special Wastes from Mineral Processing*. Slag from the primary processing of lead and of zinc were the only lead-zinc processing wastes retained within the Bevill exemption and addressed in the 1990 Report to Congress. In the subsequent regulatory determination (56 FR 27300), EPA determined that regulation of these wastes under Subtitle C was not warranted. All other lead-zinc processing wastes may be subject to Subtitle C if they are listed by EPA as hazardous wastes or if they exhibit one or more characteristics of a hazardous waste.

In response to a court order, EPA, in September 1988 (53 FR 35412), listed two lead-zinc wastes as hazardous wastes: surface impoundments solids contained in and dredged from surface impoundments at primary lead smelting facilities (K065) and sludge from treatment of process waste water and/or acid plant blowdown from primary zinc production (K066). In July 1990, however, a Federal Court of Appeals remanded these listings (*AMC v. EPA*, 31 ERC 1935).

As discussed above, wastes from the extraction and beneficiation of ores and minerals are generally excluded from RCRA Subtitle C requirements by the Bevill Amendment. EPA interprets this exclusion to encompass only those wastes uniquely associated with extraction and beneficiation activities; the exclusion does not apply to wastes that may be generated at a facility but are not uniquely related to mineral extraction or beneficiation. For example, waste solvents that meet the listing requirement as a hazardous waste under 40 CFR §§261.31 and are generated at an extraction or beneficiation facility by cleaning metal parts (i.e., activities not uniquely related to extraction and beneficiation) are considered hazardous wastes and regulated as such. These wastes must be managed as any other hazardous waste, subject to the Federal requirements in 40 CFR §§260 - 271 (or State requirements if the State is authorized to implement the RCRA Subtitle C program), including those for manifesting and disposal in a permitted facility.

1.7.1.2 Clean Water Act

Under Section 402 of the CWA (33 USC §1342), all point-source discharges to waters of the United States from industrial and municipal sources must be permitted under the National Pollutant Discharge Elimination System (NPDES). A point source is defined as any discrete conveyance, natural or

manmade, including pipes, ditches, and channels. NPDES permits are issued by EPA or delegated States.

Effluent limits imposed on an NPDES permittee are either technology-based or water quality-based. National technology-based effluent guideline limitations have been established for discharges from active lead-zinc mines under the Ore Mining and Dressing Point-Source Category (40 CFR Part 440 (Subpart J)). These regulations address point-source discharges from all types of lead-zinc extraction processes including open-pit, underground, and froth-flotation. Discharges from regulated operations must meet Best Available Technology/Best Practicable Technology (BAT/BPT) standards for cadmium, copper, lead, mercury, zinc, suspended solids, and pH. The specific effluent standards for these pollutants are summarized in Table 1-9 (for mines) and Table 1-10 (for mills). Permit writers can establish additional limitations at a specific facility based on Best Professional Judgment (BPJ). For pollutants not addressed by these guidelines, effluent limits are based solely on BPJ.

Table 1-9. BPT and BAT Standards Ore Mining and Dressing Point Source Category (milligrams per liter)

POLLUTANT	BPT Maximum for 1 Day	BPT Average of Daily Values for 30 Consecutive Days	BAT Maximum for 1 Day	BAT Average of Daily Values for 30 Consecutive Days
Cadmium	N/A	N/A	0.10	0.05
Copper	0.30	0.15	0.30	0.15
Lead	0.6	0.3	0.6	0.3
Mercury	0.002	0.001	0.002	0.001
Zinc	1.5	0.75	1.5	0.75
Total Suspended Solids	30	20	N/A	N/A
pH	6.0 to 9.0	6.0 to 9.0	N/A	N/A

Source: 40 CFR Part 440 Subpart J

The permit writer also must ensure that the NPDES permit will protect water quality. Table 1-11 identifies the Federal surface water quality criteria for lead and zinc established by EPA's Office of Water (from EPA's 1988 "Quality Criteria for Water"). Individual States are required to adopt water quality criteria at least as stringent as the Federal levels. The application of these criteria is based on the designated use of a specific receiving water (e.g., drinking water supply, aquatic life, and/or recreational use). Also, each State has been required to develop instream water quality standards to protect the designated uses of receiving waters.

Table 1-10. BPT and BAT Standards for Lead and Zinc Mills Using Froth-Flotation Alone or in Conjunction with Other Beneficiation Processes (milligrams per liter)

POLLUTANT	BPT Maximum for 1 Day	BPT Average of Daily Values for 30 Consecutive Days	BAT Maximum for 1 Day	BAT Average of Daily Values for 30 Consecutive Days
Cadmium	0.10	0.05	0.10	0.05
Copper	0.30	0.15	0.30	0.15
Lead	0.6	0.3	0.6	0.3
Mercury	0.002	0.001	0.002	0.001
Zinc	1.0	0.5	1.0	0.5
Total Suspended Solids	30	20	N/A	N/A
pH	6.0 to 9.0	6.0 to 9.0	N/A	N/A

Source: 40 CFR Part 440 Subpart J

Table 1-11. Federal Water Quality Criteria and Drinking Water Standards (in micrograms per liter)

	Fresh water Acute	Fresh water Chronic*	Marine Acute*	Marine Chronic*	Drinking Water Standard
Lead	82	3.2	140	5.6	50 (Action Level)
Zinc	120	110	96	86	5000 (MCL)

*Standards are relative to water hardness. Standards shown are for hardness 100.

Source: U.S. EPA, Office of Water, 1986

NPDES permit writers must determine whether technology-based effluent limitations are adequate to ensure that applicable water quality standards are met. Where technology-based limits are not sufficiently stringent, water quality-based effluent limitations must be developed. As a result, an NPDES permit may include technology-based effluent limitations for some pollutants and water quality-based effluent limitations for other pollutants.

Contaminated storm water runoff from some mining operations has been documented as causing water quality degradation. In the past, storm water discharges received limited emphasis under the NPDES program. However, EPA recently promulgated National regulations (55 FR 47990; November 16, 1990) that specifically address point-source discharges of storm water from industrial facilities,

including active and inactive/abandoned mine sites. These regulations require NPDES permits for all discharges of contaminated storm water from mine sites. Storm water requirements will be applied to mine sites either individually (i.e., through individual NPDES permits) or in larger groups (i.e., through general NPDES permits applicable to similar operations, possibly in particular areas).

Some discharges from mine sites do not meet the traditional definition of a "point source discharge." For example, runoff from overburden and mine development rock piles, tailings piles, and other mine areas often is not controlled through a discrete conveyance. As a result, these kinds of discharges have frequently been considered nonpoint source discharges. Under Section 319 of the CWA, States are required to prepare nonpoint source assessment reports and to develop programs to address nonpoint sources on a watershed-by-watershed basis. Each State must report to EPA annually on program implementation and resulting water quality improvements.

1.7.1.3 Clean Air Act

Under the CAA (42 USC § 4209, Section 109), EPA established national primary and secondary ambient air quality standards for six "criteria" pollutants. These are known as the National Ambient Air Quality Standards (NAAQS). The NAAQS set maximum concentration limits for lead, nitrogen oxides, sulfur dioxide, carbon monoxide, suspended particulate matter of less than 10 microns in diameter, and ozone. To attain the air quality goals set by the CAA, States and local authorities are given the responsibility for bringing their regions into compliance with NAAQS. In addition, States may promulgate more stringent ambient air quality standards. The current NAAQS for lead is 1.5 micrograms per cubic meter ($\mu\text{g}/\text{m}^3$) maximum arithmetic mean average over a calendar quarter (40 CFR §50.12). EPA is currently considering lowering this standard.

EPA also has promulgated air quality regulations that specifically address smelting operations. Since this report does not evaluate mineral processing, no further discussion of those rules are found in this report.

New Source Performance Standards, authorized under CAA §111, also have been promulgated for metallic mineral processing plants (40 CFR §60(LL)). A processing plant is defined as "any combination of equipment that produces metallic mineral concentrates from ore; metallic mineral processing commences with the mining of the ore." However, all underground processing facilities are exempt from NSPSs. Also, NSPS particulate emission concentration standards apply only to stack emissions. NSPSs require operations to contain stack-emitted particulate matter in excess of 0.005 grams per dscm. In addition, stack emissions must not exhibit greater than 7 percent opacity, unless the stack emissions are discharged from an affected facility using a wet scrubbing emission control device. However, on or after 60 days following the achievement of the maximum production rate (but no later than 180 days after initial startup), operations must limit all process fugitive emissions (meaning fugitive dust created during a processing operation though not released through a stack) to 10 percent opacity.

Prevention of Significant Deterioration (PSD) provisions of the CAA are intended to ensure that NAAQS are not exceeded. Under this program, new sources are subject to extensive study requirements if they will emit (after controls are applied) specified quantities of certain pollutants. Few mining sites are subject to PSD requirements since they typically are not predicted to emit sufficient quantities.

State ambient air standards promulgated to meet or exceed Federal NAAQS are generally maintained through permit programs that limit the release of airborne pollutants from industrial and land disturbing activities. Fugitive dust emissions from mining activities may be regulated through these permit programs (usually by requiring dust suppression management activities).

Currently, only the six criteria pollutants are regulated by NAAQS. Several other pollutants are regulated under National Emission Standards For Hazardous Air Pollutants (NESHAPs). NESHAPs address health concerns that are considered too localized to be included under the scope of NAAQS. While zinc and zinc oxide are listed under 40 CFR §61.01(b) as pollutants under consideration for possible health effects, they have not been listed as hazardous pollutants under the NESHAP program.

Under the 1990 Amendments to the CAA, Congress required EPA to establish technology-based standards for a variety of hazardous air pollutants, including lead compounds. In November 1993, EPA published a list of source categories, and a schedule for setting standards for the selected sources. Furthermore, if a source emits more than 10 tons per year of a single hazardous air pollutant or more than 25 tons per year of a combination of hazardous air pollutants, the source is considered a "major source." Major sources are required to use the maximum available control technology (i.e., BAT) to control the release of the pollutants (CAA Section 112).

1.7.2 Department of the Interior

1.7.2.1 Bureau of Land Management

Lead and zinc operations on Federal lands are carried out under two basic systems: leasing, pursuant to statutes that grant general authority applicable to specific classes of land, and mining claims under the 1872 Mining Law.

The authority to manage mineral activities on Federal lands in general is vested in the Secretary of the Interior, who has delegated this authority to BLM (Section 301 of the Federal Land Policy and Management Act [FLPMA] of 1976, 43 USC 1731). The BLM's general leasing statutes, the Mineral Leasing Act and the Mineral Leasing Act for Acquired Lands do not authorize the leasing of hardrock minerals (such as lead and zinc). "Hardrock minerals," defined in the BLM regulations in 43 CFR 3500.0-5(n) (1989), are those that are subject to location under the 1872 Mining Law.

Leasing of hardrock minerals, including lead and zinc, by the BLM is conducted pursuant to the BLM regulations at 43 CFR Part 3500. These regulations provide for the issuance of prospecting permits and for three types of leases: preference right leases, competitive leases, and noncompetitive leases. A prospecting permit entitles the holder to prospect on and explore Federal lands to determine the existence or workability of a hardrock deposit. If the permittee discovers a valuable mineral deposit, he or she is entitled to a preference right lease. Lands where the existence or workability of a valuable mineral deposit is already known, are subject only to competitive leasing, except if the deposit extends from an adjoining lease, either Federal or private, in which case the lands may be leased noncompetitively.

The BLM will also issue permits and leases for hardrock minerals on those public domain lands where the surface is administered by an agency outside of the U.S. Department of the Interior; however, the DOI will first consult with the surface managing agency (e.g., the FS). For acquired lands, and for public domain lands where required by law, permits or leases will be issued only with the written consent of the appropriate official of the surface managing agency. The permits or leases will be subject to such conditions as that official may prescribe.

As of 1989, all existing Federal lead-zinc mineral leases were located in Missouri. Federal lead-zinc leasing in Missouri is generally conducted on lands managed by the FS pursuant to the authority of Section 402 of Reorganization Plan No. 3 of 1946, 60 Stat. 1099; 5 U.S.C. Appendix (1988). However, this Act transferred certain functions of the Secretary of Agriculture over specific classes of national forest lands to the BLM. Under this authority, the BLM may issue hardrock and other permits and leases on certain National Forest System lands, but only when the FS, acting for the Secretary of Agriculture, advises that the leases or permits will not interfere with the purposes for which the lands were acquired. Leases and permits are also fully subject to stipulations imposed by the FS to protect the lands.

The FS does not currently have regulations covering issuance of leases, or for operations conducted under such leases. Instead, the FS approves permits and leases, and imposes stipulations on a case-by-case basis subject to general management standards in the FS Internal Manual.

Any lead-zinc leases issued under other statutes authorizing the issuance of hardrock leases on Federal lands would also be subject to the BLM hardrock leasing regulations in 43 CFR §§3500, 3560. These other hardrock leasing authorities, applicable to certain other FS areas and certain areas under the jurisdiction of the National Park Service (NPS), are listed in 43 CFR §§3500.0-3.

The BLM is also generally responsible for management of operations on mining claims located pursuant to the 1872 Mining Law. However, in 1876, an amendment to the Mining law was passed that made the law not applicable in the state of Missouri (30 USC §49). Mining claims for lead and

zinc, therefore, cannot be located in Missouri. However, lead and zinc are both subject to location under the Mining Law in most other public domain States.

Under the 1872 Mining Law, a person has a statutory right to go on the open (unappropriated and unreserved) public lands of the United States for the purpose of prospecting for, exploring, developing, and extracting minerals. The discovery of a valuable mineral and proper location of a claim creates broad possessory rights. In general, the BLM has authority under FLPMA to regulate mining claims to prevent "unnecessary and undue degradation" of the Federal lands and resources involved.

The BLM's general surface management regulations governing mining claim operations, which include lead and zinc operations, are found in 43 CFR §3809. These regulations cover general operating and reclamation standards, bonding requirements, environmental review requirements, and remedies for noncompliance. The regulations establish three general use categories for mining operations, each subject to different levels of oversight by the BLM. These categories are casual use operations (i.e., those that normally result in only negligible disturbance of Federal lands and resources and that require no prior notice to or approval from the BLM); notice-level operations (i.e., those that involve disturbance of five acres or less, for which the operator must notify the BLM prior to commencing surface disturbing activities); and plan-level operations (i.e., disturbances of greater than five acres, and operations in some specified areas, for which the operator must obtain BLM approval of a plan of operation prior to commencing activity).

All mining operations of whatever level are subject to monitoring by the BLM to ensure that no unnecessary or undue degradation is occurring, and all operators are responsible for reclaiming the area of their claim. Activities conducted under either a notice or an approved plan of operation are subject to regulatory standards governing access, waste disposal, and reclamation.

The current BLM policy concerning bonding requirements for operations under the Mining Law is established by an internal BLM Instruction Memorandum issued on August 4, 1990. This Instruction Memorandum sets standards for reclamation bonds for all plan-level operations, including acceptance of State bonds in lieu of a BLM bond if the State bond is within 75 percent of BLM's estimated reclamation costs or BLM's bond requirements. A bond will not ordinarily be required for notice-level operations or for casual use. The BLM will, however, require any operator with a history of noncompliance to post a 100 percent reclamation bond, regardless of existing State bonds.

1.7.2.2 National Park Service

Limited authority exists for leasing of hardrock minerals on certain areas under the jurisdiction of the NPS. Hardrock leasing, where allowed, is regulated under the BLM's general hardrock leasing regulations in 43 CFR §§3500, 3560, discussed above, as well as under special provisions in 43 CFR

§§3582, 3583. The consent of either the NPS Director or the Secretary of Agriculture, depending on the area, is required prior to lease issuance.

The Mining in the Parks Act of September 28, 1976, prohibits the location of new mining claims in National Parks and Monuments. The NPS has the authority under this Act to regulate and control operations on existing claims, and on claims already patented, to ensure that any valid existing rights under them are exercised in a manner consistent with the purposes for which the particular NPS area was created. The NPS regulations in 36 CFR §9(A) govern surface and water protection, access permits, claim recordation, assessment work, and reclamation. Operators must receive approval of a plan of operation from the appropriate Regional Director prior to commencing activity. All operations, once approved, must be covered by either a reclamation bond or a security deposit.

1.7.2.3 Fish and Wildlife Service

The FWS manages a variety of lands, including those within the National Wildlife Refuge System. Leasing of Federal minerals on FWS lands is allowed only where compatible with the major purposes for which a specified area was established, and is then fully subject to the imposition of restrictive lease terms pursuant to the BLM's leasing regulations.

The prospecting, locating, or filing of mining claims on FWS lands is generally prohibited. Where mineral rights have been vested in private parties prior to the acquisition of the lands by the United States, the FWS regulations (in 50 CFR §29) require that, to the greatest extent possible, all exploration, development, and production operations be conducted in such a manner as to prevent environmental and other damage to the lands, waters, facilities, and vegetation of the area. Operations must comply with applicable environmental laws, and all wastes and contaminating substances must be kept to the smallest practicable area. Upon cessation of operations, the area must be restored as nearly as possible to its original condition. The FWS regulations do not impose specific technical operational or reclamation standards, and do not specify bonding requirements.

1.7.3 Department of Agriculture

1.7.3.1 Forest Service

As described above, limited authority exists for leasing hardrock minerals, including lead and zinc, on certain specified lands managed by the Forest Service (FS). Hardrock leases on FS lands can generally be issued by BLM only with FS consent and are also subject to imposition of protective stipulations by the FS. Since the FS does not currently have regulations governing operations under hardrock leases issued by the BLM on FS lands, consent to lease and applicable stipulations are determined on a case-by-case basis. The leases are otherwise governed by applicable BLM regulations found in 43 CFR §3500, 3560.

The FS does, however, have regulations governing operations under mining claims on FS lands. The FS regulations (36 CFR §228), rather than the BLM's Mining Law regulations, govern activities under mining claims on FS lands. These FS regulations generally mandate that operations under mining claims be conducted to minimize adverse environmental impacts in national forests.

The FS regulations are similar to the BLM regulations and provide for FS consultation with appropriate agencies of the Department of the Interior in reviewing technical aspects of proposed plans of operation. The FS regulations require that persons proposing to initiate any operations that might cause disturbance to surface resources must first file a notice of intent to operate with the District Ranger having jurisdiction over the area to be affected. Upon a finding by the District Ranger that the operations will likely cause significant disturbance of surface resources, the operator must submit a proposed plan of operation. Neither a notice of intent to operate nor a proposed plan of operation is required for the following activities: locations or markings of mining claims; mineral prospecting or sampling that will not cause significant surface disturbance; operations that do not involve the use of mechanized equipment or the cutting of trees; or uses that will be confined to existing roads.

Proposed plans of operation must include a thorough description of the proposed site, the nature of the proposed operations, and measures for meeting environmental protection requirements. The FS will conduct an environmental analysis of the proposed plan of operation, and if necessary, will prepare a National Environmental Policy Act (NEPA) environmental impact statement (EIS).

The regulations require that all operations be conducted to minimize, where feasible, adverse environmental impacts on national forest resources, and to comply with applicable environmental laws. The regulations specify standards for reclamation and provide that the District Ranger may require a reclamation bond.

1.7.4 State Programs

1.7.4.1 Alaska

Alaska's environmental programs are managed by the Alaska Department of Environmental Conservation (DEC). Although the State of Alaska has only one lead-zinc mine, the Red Dog Mine located 52 miles from the northwestern coast of Alaska, this mine is one of the world's largest lead-zinc mines. Because of the sensitive environment, and because it is a massive sulfide deposit, the mine has the potential for posing significant environmental impacts if not carefully managed. The concentrate produced by this operation will be exported for processing to Canada, Europe, and the Far East (Alaska Division of Geological and Geophysical Surveys, 1989). Regulations to minimize the environmental impacts of the Red Dog mine are a mix of State, Federal, and local authorities. The permitting of the mine involved three distinct parts: the mine itself, which is located on private

land; the access corridors, which are located on Federal land; and the loading facility and port, which are located on private and State land.

The mine and associated facilities (mills, housing, etc.) are located on lands owned by the NANA Corporation, a regional native corporation under the Alaska Native Claims Settlement Act. The operator of the mine, Cominco, Ltd., has an agreement with the NANA Corporation that includes, among other things, requirements for reclamation of the site and the protection of wildlife and subsistence resources along the road corridor and the port site. These requirements between a private land owner and the mine operator are not discussed here; rather, this discussion is limited to the State and Federal authorities in place at the mine. Of note is the fact that the mine was not required to develop a closure plan or to post reclamation bonds.

Waste Water Discharge

The Alaska DEC has authority to regulate discharges. Because the State of Alaska does not have a delegated NPDES program, the DEC has the following options to regulate discharges:

- Issue a Waste Water Discharge Permit under State authority
- Certify or deny certification to the NPDES permit
- Take no action

At the Red Dog Mine, DEC issued certification of EPA's NPDES permit and, at a later date, issued a separate permit for nonpoint-source discharges (Wightman, 1991).

The mine also has a "Wetlands Permit" issued by the U.S. Army Corps of Engineers in consultation with the FWS. Many of the typical land management agency concerns (reclamation, slope stability, etc.) are considered in the wetlands permit.

Fisheries Protection

The Alaska Department of Fish and Game (ADF&G) has the authority to protect fisheries when development **threatens** to restrict fish access through a water body, or when **anadromous** fish (salmon or **steelhead** trout) or their habitats are threatened in any manner. The ADF&G issued many "Title 16" permits to maintain water flow, water quality, and habitat in fish-bearing streams throughout the project area.

Other State Permits

In addition to the permits already discussed, Alaska has other permit requirements, including a Dam Safety Permit and a right-of-way permit, both issued by the Alaska Department of Natural Resources. The Dam Safety Permit requires certification that the tailing dam is structurally sound and can

withstand storm water events. The right-of-way permit provides for design standards to minimize adverse effects, primarily to prevent nonpoint-source pollution.

1.7 4.2 Missouri

In October, 1990, the Missouri Department of Natural Resources (DNR) proposed rules governing the mining of metallic minerals in response to the State's Metallic Minerals Waste Management Act (MMWMA), passed on July 6, 1989 (Missouri Department of Natural Resources, 1991). The rules implementing the MMWMA are published in the State's Code of Regulations and took effect on April 29, 1991. According to the rules, metallic mineral mining activities, including lead-zinc operations, will be regulated through Metallic Minerals Waste Management (MMWM) permits during their active lives and through closure and post-closure. To obtain a permit, operations must comply not only with the new requirements under the MMWMA, but also with all other applicable environmental quality programs and permits. Compliance with other program requirements may be considered a condition of the MMWM permit.

Permit Applications

The State regulations require MMWM permit applicants to submit detailed information on site characteristics, including maps of the site and surrounding properties, with potential waste management areas specifically designated. Geological features that could relate to surface and ground water quality or dam stability must also be included on maps. Applications must include information on all known water wells and uses in the area, and a geological cross section of the area showing well depths, the presence of ground water, and other information.

Closure and inspection-maintenance plans are required with permit applications. Closure plans must address the design, construction, and maintenance of waste control structures, tailing dams, waste stockpiles, and supporting facilities. Mine operators must also obtain State dam safety permits through the State's Division of Geology and Land Survey if tailings dams (or other dams) reach 35 feet or more in height. Tailings piles must be sloped and graded, and repairs must be made to sloped faces that experience erosion. The methods for long-term control of surface water runoff and the protection of ground water must be included in closure plans.

Site reclamation is ensured through financial assurance measures that prospective operators must provide as part of the permit application process. Financial assurance must be provided in amounts up to \$1,000 per acre of the waste management area, but not less than \$20,000 per permit. Mine operators have the option of either presenting formal proof of assets held to guarantee reclamation of the site or setting aside funds in a company-held bond. Operators are required to update this financial assurance within 90 days of the close of each succeeding fiscal year.

Under the MMWMA, permit fees (\$10,000 at initial application and \$2,500 annually thereafter) and funds from forfeiture of bonds are placed in a "Metallic Minerals Waste Management Fund." This fund is used to administer and enforce the MMWMA program and to manage the remediation of "metallic minerals waste management areas."

Water Quality

The State is authorized to implement NPDES program requirements as described in 40 CFR §123(A). All surface waters in the State are classified according to one or more of seven designated uses. State water quality standards have been established to protect each of these designated uses. Lead-zinc tailings have been specifically identified by the State as one of the five important sources of water quality degradation.

In addition to requiring operations to obtain NPDES permits, MMWM permits require mine operations to implement ground water protection practices. Operators must submit a ground water monitoring plan as well as an analysis of background ground water quality, specifications for monitoring wells, and the implementation of a ground water sampling program. Monitoring will continue throughout the active life of the site, closure, and an inspection-maintenance period. A ground water monitoring point must also be established. Water contaminants at this point cannot exceed standards established under Missouri law to meet Federal requirements for drinking water.

Air Quality

State air emission requirements and ambient air quality standards are the same as Federal requirements. The State has also adopted all of EPA's NSPS and hazardous air pollutant standards given in 40 CFR §60-61, including all the mining industry standards. Mining operations emitting regulated pollutants must obtain major and minor source permits that specify emission limits. In addition to requiring air quality permits as a precondition to obtaining a MMWM permit, MMWM permits will specifically require the use of fugitive dust control techniques such as water spraying, chemical binders, anchored mulches, vegetation, and physical containment.

Wetlands Protection

The State has no wetlands protection regulations. Operations impacting wetlands are governed by Federal regulations.

Abandoned Mine Reclamation

The States's Mine Reclamation and Restoration Rules found at Title 10 of the Missouri Code of State Regulations established a program for the reclamation of noncoal mine sites that were abandoned before August 3, 1977. To qualify for reclamation, these sites must be determined to present a threat to public health, safety, and welfare. These sites are reclaimed by the DNR using State funds.

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APPENDIX 1-A

**SPECIFIC FLOTATION ACTIVITIES EMPLOYED FOR POLYMETALLIC ORES
AND ASSOCIATED PROCESS FLOW SHEETS**

St. Joe-Balmat; Balmat, New York (Figure 1-4)

The St. Joe-Balmat concentrator has introduced a talc prefloat circuit system before flotation. In this process, a light alcohol frother is used to float the talc from the ore. Four 8.4 m³ roughers and two stages of cleaning are used to reduce the calcium and magnesium content of the ore by 50 percent. Some zinc, however, may be lost in this process as well.

The facility uses eight 8.4 m³ flotation cells for roughing and scavenging (White and Clifford, 1977). Four stages of lead concentrate cleaning are also used. Sodium ethylene xanthate is used as a lead collector, and cyanide is used as a sphalerite depressant. The facility generates a concentrate that is 57 percent grade and is recovered at a rate of 62 percent.

Tailings from the lead circuit are conditioned with copper solution (to activate sphalerite), sodium ethyl xanthate, a collector, frother, and lime to float zinc minerals. Three stages of zinc concentrate cleaning are also used. Zinc concentrate is generated at the facility at a grade of 58.7 percent and is recovered at a rate of 92.8 percent.

Magmont Mill; Bixby, Missouri (Figure 1-5)

At the Magmont facility, lead and copper minerals are first floated together in bulk concentrate in a series of six roughers and five scavengers (Sharp, 1976). An 11 cell cleaner circuit is subsequently employed. The cleaned bulk concentrate is then sent to a copper separation circuit where it is treated with sulfur dioxide and starch to depress the lead minerals. The copper minerals are floated and cleaned three times to generate a final copper concentrate. The underflow from the float is the final lead concentrate.

The tailings from the copper-lead roughers, and sometimes the tailings from the copper-lead scavengers, are treated with copper sulfate and floated to generate a zinc concentrate. The concentrate then undergoes four stages of cleaning to produce the final zinc concentrate.

Kerramerican-Blue Hill; Blue Hill, Maine

The Kerramerican-Blue Hill zinc concentrator first uses thirty 1.12 m³ flotation cells for copper roughing and scavenging (White and Clifford, 1977). Reagents, such as Z-200, Z-242, and Z-3501 (collectors) and sodium sulfite (zinc depressant) are used to produce copper concentrate.

The tails from the copper flotation process feed the zinc flotation system. A total of 32 cells are used in the zinc circuit; 16 1.4 m³ cells are used for roughing and 16 1.1 m³ are used for zinc scavenging. This is followed by two stages of zinc concentrate cleaning. The facility generates a zinc concentrate that is 53 percent grade and is recovered at a rate of 93 percent.

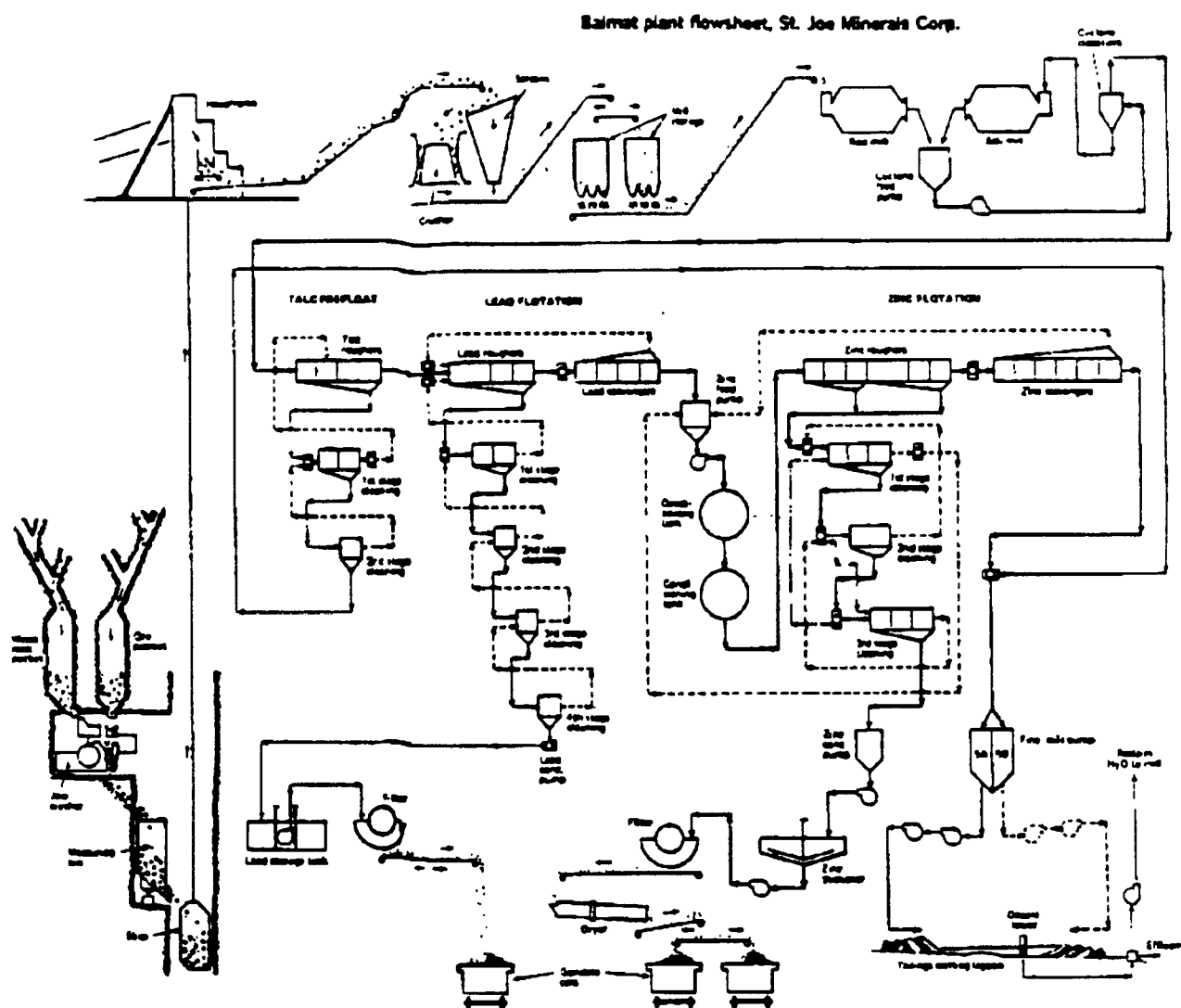


Figure 1-4. St. Joe Corporation-Balmat Plant Flow Sheet

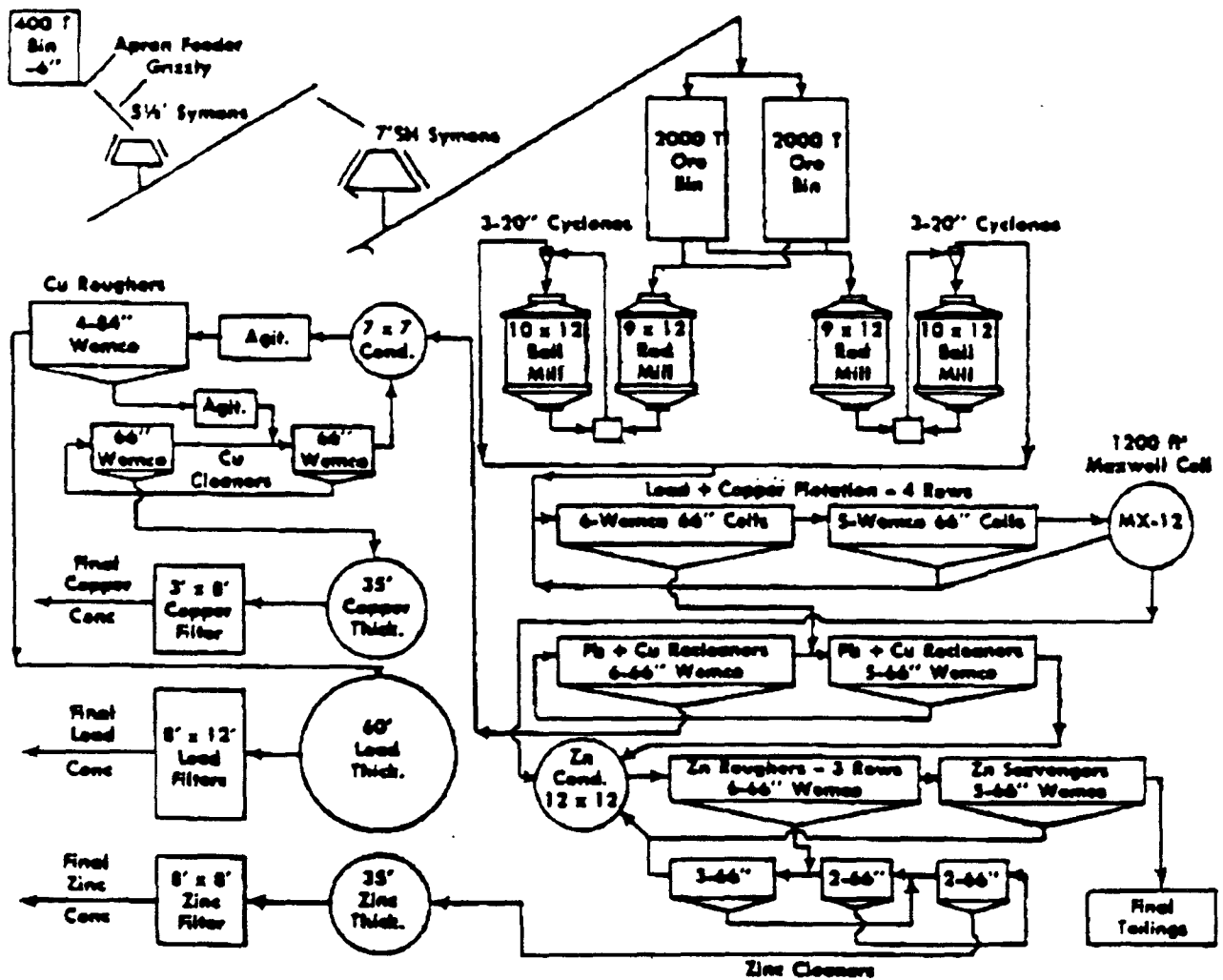


Figure 1-5. Flow Sheet of the Magmont Concentrator

Doe Run Company Brushy Creek Concentrator; Viburnum, Missouri

The St. Joe-Brushy Creek facility uses eight 8.4 m³ flotation cells for lead roughing and eight 1.7 m machines for concentrate cleaning and recleaning (White and Clifford, 1977). Sodium isopropyl xanthate is used as a lead collector and zinc sulfate as a zinc depressant. The facility generates a lead concentrate that is over 74 percent grade and is recovered at a rate of 97 percent. Copper is also produced as a byproduct of lead-copper flotation.

Tailings from the lead circuit are conditioned with a copper reagent, Z-200, and a frother in preparation for zinc flotation. Six 8.4 m³ flotation cells are used for zinc roughing and nine 1.7 m machines are used for three stages of zinc cleaning.

ASARCO Young Mill; Mascot, Tennessee

The ASARCO Young Mill uses reagents such as sodium aerofloat, aerofloat 211, and copper sulfate in nine 8.4 m³ flotation cells for zinc scavenging (White and Clifford, 1977). Two stages of zinc concentrate cleaning are also used. The facility generates a zinc concentrate that is 59.6 percent grade and is recovered at a rate of 91 percent.

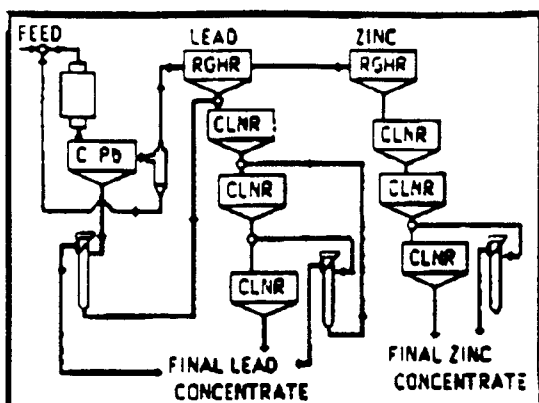


Figure 1 - Pilot Column Flotation Tests at Polaris

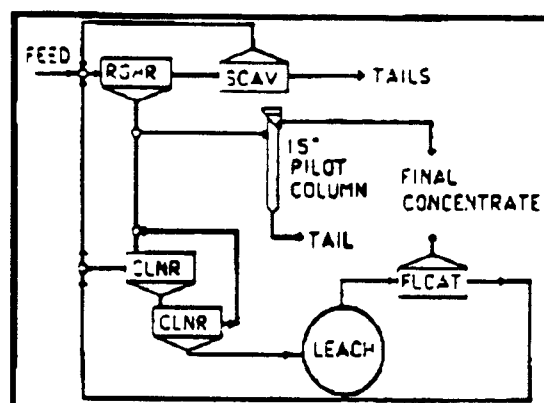


Figure 3 - Pilot Column Flotation Cell at Pine Point

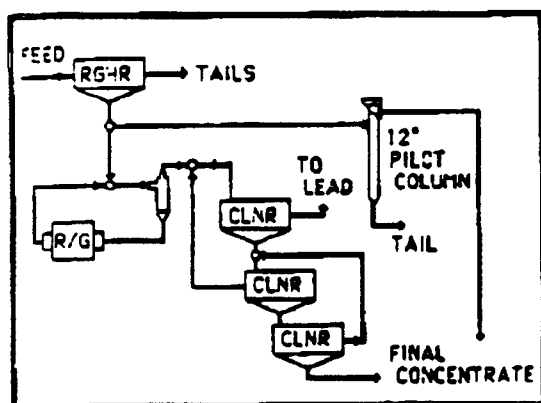


Figure 5 - Pilot Column Flotation Tests at Sullivan

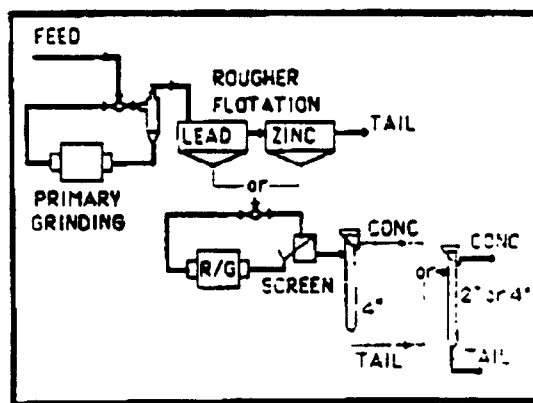


Figure 6 - Pilot Plant Flowsheet

Figure 1-6. Flow Sheet of Four Polymetallic Flotation Operations

APPENDIX 1-B

NPL SITE SUMMARIES

RELATED TO LEAD AND ZINC EXTRACTION AND BENEFICIATION

(from "Mining Sites on the National Priorities List,

NPL Site Summary Reports Volumes I-V, Environmental Protection Agency,

June 21, 1991.)

IRON MOUNTAIN, SHASTA COUNTY, CALIFORNIA

Operating History

The Iron Mountain Mine site is a 4,400-acre underground and open-pit mine complex in the southeastern portion of the Klamath Mountains in the West Shasta Copper-Zinc Mining District, nine miles northwest of Redding, California. The mine is owned by Iron Mountain Mines, Inc., but Stauffer Chemical Company, the previous mine owner, owns the surrounding land.

Iron Mountain Mine was used for the mining and beneficiation of copper, silver, gold, zinc, and pyrite from 1865 to 1963. Deposits of silver and copper were mined prior to 1900. Processing of copper and silver was conducted between 1896 and 1907 at the Keswick smelter. The smelter may have been located near Spring Creek and the Sacramento River. No other smelting operations occurred at the mine site.

Starting in 1900, pyrite ore from the so-called "old mine" was sold for offsite beneficiation. The Number 8 mine and the Hornet mine were developed in 1907. Pyrite ore from the "old mine" and Hornet mine was sold for production of sulfuric acid. Residues from this process were returned to the Keswick smelter for recovery of copper, silver, and gold.

Between 1914 and 1919, a copper flotation mill operated at the town of Minnesota, approximately two miles east of the above mines. Copper and pyrite ore tailings were disposed in this area. The mill was moved to an area adjacent to the Number 8 mine and operated between 1928 and 1933. A tailings dam was built in Slickrock Creek, but was destroyed in a 1933 flood.

Open pit mining of gold and silver required tailings disposal in a gulch adjacent to Slickrock Creek. Approximately 2.6 million tons of ore were processed in this area between 1929 and 1942.

The Richmond and Mattie ore bodies were developed for their copper and zinc deposits. The Richmond ore body was mined between 1942 and 1956; the Mattie ore body was developed in 1942. A copper-zinc flotation plant operated in this area between 1943 and 1947. The Brick Flat ore body was mined for pyrite between 1955 and 1962 using open pit methods.

All mining at the site was discontinued in 1963. However, several activities are still in operation. Two cementation plants, the Boulder Creek Cementation plant constructed in 1940 and the Slickrock Cementation plant constructed in 1977, and recovery of copper from acid mine drainage (AMD). Other metals, including cadmium and zinc, are not recovered. The Spring Creek Debris Dam, constructed in 1963 to control the discharge of contaminated runoff into the Sacramento River, is operated by the State.

Environmental Damages and Risks

Mine disturbance has enhanced the natural action of bacteria that accelerates the formation of acid mine drainage containing toxic metals. The drainage occurs when precipitation infiltrates the highly fractured igneous and metamorphic rock on the top of the mountain. The Richmond and Hornet portals are the major sources of acid and heavy metals. Discharge from the Richmond portal has registered pH values as low as 0.6.

Discharges from the Richmond portal drain into Boulder Creek, a perennial stream. Others drainages from the mine and intermittent drainages from uncovered tailings and waste piles flow into Slickrock

Creek. There is also acid mine seepage along a 300- to 400-yard debris slide, which diverted the original Slickrock Creek drainage. Both Boulder and Slickrock Creeks are tributaries to Spring Creek (see Table 1-12), which drains into Keswick Reservoir, just upstream of the Keswick dam.

Table 1-12. Water Quality Characteristics at Spring Creek

Constituent	Concentration
ph	3.0
Cadmium	0.05 to 0.3 mg/l
Copper	3 to 15 mg/l
Iron	50 to 350 mg/l
Zinc	10 to 80 mg/l
Flow rate	5 to 1,000 ft ³ /s

An estimated average of 1,466 pounds of zinc, 423 pounds of copper, 4,800 pounds of iron, and 10 pounds of cadmium are discharged each day into the Keswick Reservoir from the Iron Mountain Mine.

The creeks are nearly devoid of aquatic life. Heavy metal precipitates have been found in sediments in Keswick Reservoir. A 1980 survey on the density and distribution of aquatic invertebrates in Keswick Reservoir showed that invertebrate numbers were significantly reduced downstream from the Spring Creek arm of the reservoir. Fish in the Sacramento River at Keswick have concentrations of copper and cadmium in liver tissues exceeding levels found to be detrimental to fish reproduction. Loss of salmonoids in the Sacramento River from copper and zinc toxicity was first noted in 1944. At the time, pyrite was being sold for sulfuric acid manufacture and copper was produced sporadically.

Fishkills, which are the result of inadequate dilution of Spring Creek water, have occurred periodically since then. The problem has been magnified by the completion of Shasta Dam, which reduced upstream dilution flows in the Sacramento River.

CALIFORNIA GULCH, LEADVILLE, COLORADO

Operating History

The Phase I Remedial Investigation (RI) study area, which includes the City of Leadville (population 3,800), encompasses an 11.5-square mile watershed that drains along California Gulch to the Arkansas River west of Leadville. The development of Leadville dates back to the 1850s with the mining development of the rich mineralized zones containing principally gold, silver, lead, zinc, and copper. Mining, processing, and/or smelting operations in the area have been active for more than 125 years and varied in degree with economic demand and technological improvements. Early activities consisted of placer mining for gold in California Gulch. Later, underground mines were

developed to the southeast of Leadville where the ores were extracted and then processed into metallic concentrates. These concentrates were either shipped elsewhere or further processed at the numerous smelters that were in the Leadville area. Many areas received mining-related wastes including mine waste rock, tailings, and slag piles.

As the mines were deepened and mining areas expanded, drainage became an economic factor in the operational costs, particularly during periods of depressed metal prices or labor unrest. Tunnels were developed to drain the ore bodies and to facilitate mining. The Yak Tunnel, which started in 1895 as an extension of the Silver Cord Tunnel, eventually reached a length of 3.5 miles and was the first of two major efforts to improve drainage.

The Yak Tunnel was extended several times and has several laterals and drifts that extend into the various mine workings. The last extension was in 1923. EPA estimates that 60,000 feet of tunnels and major laterals and 55 to 74 million cubic feet of void space are associated with the tunnel mining activities. Although mining activity has ceased in the immediate area of California Gulch, other mining areas are active and continue to drain into the Yak Tunnel.

The current condition of the Yak Tunnel is unknown. However, the last inspection, conducted by the American Smelting and Refining Company (ASARCO) in 1983, disclosed that the tunnel roof was generally weak and had caved in at many places.

Environmental Damages and Risks

The RI Report, completed in May 1987, presents a human risk assessment for the site and concluded that exposure to contaminants at the site presented a threat to human health. The risk assessment identifies cadmium, copper, lead, and zinc as the contaminants of concern at the site. California Gulch and the City of Leadville are in Lake County, a relatively small (380-square mile) rural area with a current estimated population of approximately 6,600. Lake County, and the surrounding area, depends on agricultural, tourist, and mining industries. Its past employment and economic base stemmed primarily from mining and mine-related industries, which have diminished significantly since 1977. Mine lay-offs have dramatically reduced employment in Lake County.

The RI Report stated that there is little specific information on wildlife within the site study area. The wildlife found within the study area should be similar to that found in the general Leadville area. However, the disturbed landscape and level of past and present human activity in both Leadville and the California Gulch area may tend to minimize the number and diversity of wildlife within the site.

Ground water monitoring indicated that the upper 25 to 50 feet of California Gulch alluvial ground water are contaminated with cadmium, zinc, and other metals and pollutants such as sulfates, which are associated with the Yak Tunnel discharge. The concentrations of various metals in ground water are in excess of both primary and secondary drinking water standards.

Surface water contamination is the primary concern for the Yak Tunnel operable unit. During the Phase I RI studies, EPA identified 33 existing wells that were drilled into the California Gulch alluvium. Many of these wells have been abandoned because of poor water quality. In 1986, EPA connected the one remaining household that used the aquifer as a drinking water source to the public water system. However, at this time, no steps have been taken to prevent people from using their existing wells or from drilling wells into the contaminated alluvium.

EAGLE MINE, MINTURN/REDCLIFF, COLORADO

Operating History

Mining activities in the Eagle Mine area began in the 1870s. Several individual mines were located in the area where the Eagle Mine facility now exists. Mining of oxidized gold-silver ore in the Gilman area (area between the towns of Minturn and Red Cliff) was begun in 1884 and ceased in 1894. By 1905, mining of the zinc deposits had begun, and a roasting and magnetic separation plant (roaster plant) had been set up in Belden to refine the ore mined from what is the present-day Eagle Mine. In 1912, the New Jersey Zinc Company began consolidating the various mines into one facility (Eagle Mine). New Jersey Zinc operated the roaster plant at Belden as part of the Eagle Mine facility from 1915 to 1919 when the plant was dismantled. Wastes from the roaster plant were dumped along the side of a mountain and allowed to migrate into the Eagle River.

A separate mill, consisting of an underground froth-flotation unit designed to treat zinc ore, was constructed in 1929. Waste material from this mill was transported in slurry form through a buried concrete pipeline to a location near the Rex Flats wetlands area. At this point, the pipeline became an elevated wooden stave pipeline that carried the waste (tailings) to the old tailings pond. Because of the lack of a market, the zinc mill was closed in 1931. By 1941, mining of zinc ore was re-established, and after 1946, onsite milling of the ore was initiated.

Copper-silver ore was mined from 1932 through 1940. In fact, copper-silver ore was the only ore mined during those years. However, this ore was not processed at what is now the Eagle Mine site. Mining of copper-silver ore was continued until October 1984, but with an inactive period between 1981 and 1983.

In the 1960s, New Jersey Zinc merged with Gulf and Western Company. Gulf and Western operated Eagle Mine through a subsidiary, New Jersey Zinc Company (Delaware Corporation), from 1966 to 1981. By the end of 1977, milling operations at the site had ceased and the mill facility was converted to an acid mine water treatment facility. However, from September 1983 until June 1984, some mining did occur. Mr. Glen Miller and Battle Mountain Corporation (new owners) extracted copper and silver ore. In June 1984, the facility was abandoned by Miller, and electricity to the mine was shut off, thereby shutting off the pumps. The mine began to flood at that time and has continued to flood.

Environmental Damages and Risks

The results of the RI of the Eagle Mine site show damage to plant and animal life in and around the site and contamination of drinking water (private wells) by metals. The RI also indicates that there has been a decrease in recreational use and fishing in the Eagle River as a result of metals contamination.

Three private drinking water wells were contaminated with heavy metals. Two wells (#1 and #3) are no longer in use, and the other (well #2) is in use only for household cleaning purposes and not for drinking water.

Other uses of Eagle River water are for municipal supply (for the Town of Minturn and many others in the area), stock watering, and irrigation downstream from the confluence with Gore Creek. The major consumer of water is the Consolidated Upper Eagle Valley Sanitation District. The river water is also drawn from several alluvial wells bordering the river. The Town of Minturn, located north of

the Eagle Mine, diverts surface water for municipal use. In addition, Minturn has two municipal wells located in Maloit Park. However, these wells were tested in April and May 1985, and no hazardous metals were found in the samples taken. As of 1985, when the RI was written, there were also several other municipal water systems planned that would divert water from the Eagle River.

Aquatic organisms were found to be affected by the of metals in the river. Bioaccumulation of zinc, copper, lead, and cadmium was evident in macroinvertebrates taken from the Eagle River and its tributaries. Of the four metals, zinc was found to have the most influence on the aquatic environment. Surface water concentrations of zinc exceeded chronic toxicity (0.047 mg/l) and acute toxicity (0.18 to 0.57 mg/l) criteria in the Eagle Mine area. Many times, zinc levels were found to be two to three times the toxicity criteria concentrations. Cadmium and copper concentrations often exceeded acute toxicity criteria (cadmium - 0.0018 to 0.0086 mg/l; copper - 0.0092 to 0.0340 mg/l) and lead exceeded the chronic toxicity criteria (0.00130 to 0.0077 mg/l). The macroinvertebrate community was seriously affected from the old tailings pond/Rex Flats reach to Cross Creek. Below the mine facility, an important component of the Eagle River benthic community, mayflies, was reduced in number at all sampling periods.

Fish population studies were conducted in the summer of 1985. The fish community is dominated by a brown trout population that was found to be reduced in number in streams receiving discharges from the Eagle Mine and from the old tailings pond/Rex Flats (as compared to upper Cross Creek and upper Eagle River numbers). Trout populations were also reduced below Rock Creek. Although the trout biomass below Cross Creek indicated partial recovery, it generally remained below the biomass found in upper Cross Creek and the upper Eagle River.

The Eagle River is no longer able to support a quality fishery because of the environmental degradation from heavy metals. The macroinvertebrate food base has been severely reduced from the Eagle Mine facility to Cross Creek and recovers slowly between Cross Creek and Gore Creek. Although the trout population has acclimated to some degree to the metals concentrations in the Eagle River, they have not been able to survive in the reaches where contamination is worse. Even in the river areas where the trout do exist, the reproduction and growth potential of the trout is reduced by lack of food and chronic toxicity by heavy metals.

The loss of several miles of trout habitat affects the local economies, especially those dependent on recreation and tourism. The Division of Wildlife has expended funds in attempting to restock the river and has expended additional funds leasing public access to the Eagle River.

There are several conditions at the Eagle Mine site that adversely affect the soil, and therefore the plant and animal life at the site. The soils at the site contain heavy metals and are highly acidic. Mobility of the metals is affected by acidity, electrical conductivity, and the presence of sulfates. Soil acidity, or pH, is one of the most important parameters in controlling the availability of metals to plants. As the pH decreases, the metals solubility increases, increasing the potential for the metals to become more available to plants. Because the metals are mobile, they have collected through transport by runoff in the Maloit Park wetland, the banks of the Eagle River, and Rex Flats. At these locations, the metals have been available to plants in phytotoxic levels. Many areas are bare of vegetation and, therefore, erosional forces have taken over and increased the rate of sediment transport.

The vegetation at the Eagle Mine site has been visibly affected by metals contamination. For example, plants have been discolored, stunted in growth or deformed, or have not germinated in certain areas. Other observed effects were lower plant density and less diversity.

Investigations of the small mammal species at the Eagle Mine site showed lead and cadmium concentrations higher than the concentrations found in species outside the mine site. In addition, the numbers of different species, such as deer mice, were lower in the contaminated areas than in uncontaminated areas. Evidence gathered indicates mobilization of lead and cadmium from the source(s) (tailings pond) to vegetation, and then to small and large mammals. Studies indicate that deer and elk have come into direct contact with contaminated vegetation. Human health hazards exist in the possibility of human consumption of cattle that have grazed on contaminated pastures, and human consumption of deer and/or elk obtained from sport hunting.

SMUGGLER MOUNTAIN, PITKIN COUNTY, COLORADO

Operating History

Mining, milling, and smelting of silver, lead, and zinc were conducted at the site. In the late 1800s and early 1900s, mining companies ran extensive mining operations onsite. Although several small operations started and stopped after 1930, records indicate that the bulk of the mining wastes at the site were placed on the steep slope of the western side of Smuggler Mountain near the Smuggler shaft from 1880 to 1915. In the mid-1960s a reprocessing facility was run at the site, causing the dispersion of the wastes from the relatively distinct piles at the mine site to other locations in the vicinity. Reprocessing also spawned a number of settling ponds around the site. The wastes were dispersed further by subsequent residential development. It is believed that the mined metals (silver, lead, and zinc) were reprocessed.

Mine wastes, such as waste rock, tailings, and slag, comprise much of the site. It is estimated that approximately 2.4 million cubic yards of these waste materials were generated at the site. The wastes have been spread over a wide area and at depths varying from one to two feet to 40 feet. They occur covered, uncovered, or mixed with native soil, and contain high levels of minerals containing lead and cadmium, among other constituents.

Environmental Damages and Risks

The site was first considered to pose risks in 1981, when research into crop uptake of trace metals indicated a potential problem with the uptake of lead and cadmium by vegetables grown on regraded mine and mill tailings.

Presently, the potential for human exposure exists through direct contact of soils and inhalation of contaminant-laden dusts. The risk of ingesting drinking water contaminated by site soils also exists, although because of site conditions (i.e., soil and pollutant characteristics), the potential for exposure is significantly reduced.

Lead and cadmium are the two metals of most concern at the site because of their elevated concentrations at the site and acute toxicities. Lead exposure is of specific concern to children ages one to five who have the greatest risk of exposure through soil ingestion and have a greater susceptibility to blood lead poisoning. It should be noted that toxic effects of lead ingestion in children from lead-based paints (i.e., elevated blood levels) have been documented, but exposure to lead in tailings and soil such as that at the Smuggler site has not been documented.

Cadmium can also be acutely toxic and cadmium compounds are generally more bioavailable than lead compounds. A ground water sample of 13 $\mu\text{g/l}$ of cadmium exceeded the ambient water quality

standard of 10 $\mu\text{g/l}$ in one well on one occasion. The well was checked again and found to be less than 10 $\mu\text{g/l}$. Therefore, it is unclear whether cadmium contamination exists onsite.

BUNKER HILL MINING AND METALLURGICAL COMPLEX, SMELTERVILLE, IDAHO

Operating History

Lead and zinc mining began on the Bunker Hill site with the location of the Bunker Hill and Sullivan claims in 1885 by Noah Kellogg. The first mill was constructed in 1886 in Milo Gulch in the southeastern portion of the site. The Bunker Hill and Sullivan Mining and Concentrating Company was incorporated in 1887 (the name was changed to the Bunker Hill Company in 1956). A larger mill was constructed near the site of Kellogg Tunnel in 1891. Before the Kellogg tunnel was completed in 1902, ore was transferred from the mines in Milo Gulch to the mill site by aerial tramway. The first mill located at the present mill site was constructed in 1912. Milling or concentration was originally accomplished by gravity separation. Flotation was added in 1913, and by 1938, all gravity separation was discontinued. The mill was modified to expand production in 1941 and 1947 (the types of modifications were not specified).

Originally, tailings from the mill were discharged to the South Fork of the Coeur d'Alene River and its tributaries. In 1928, the first impoundment at the Central Impoundment Area began operation. The decant from this area flowed directly into the river until 1974, when the Central Treatment Plant was installed.

The Bunker Hill Company purchased Hecla Mining Company's interest in the Zinc Plant and consolidated both plants under one ownership in 1955. In 1968, the Bunker Hill Company was purchased by Gulf Resources and Chemical Company (Gulf). Gulf operated the plant until its closure in December 1981. In 1982 the complex was sold to Bunker Limited Partnership, its present owners. In 1983, the Bunker Hill Mill and an associated mine offsite were reopened. However, in 1986, the mill and mine were shut down because of continuing depressed silver prices. At this time, active operations at the complex include the mine pumps, a waste water treatment plant, and a zinc concentrate dryer (under lease to another mining company). The mine and mill were reopened in 1988 when metal prices improved.

Environmental Damage and Risks

The Bunker Hill site contamination was brought to public attention in 1974 when symptoms of lead poisoning in children were reported to local public health officials. More than 98 percent of 172 children living within one mile of the smelter had blood lead levels exceeding 40 $\mu\text{g/dl}$ at the time of the study. CDC's safe limit is 25 $\mu\text{g/dl}$ and the World Health Organization (WHO) has determined that the no-detected effect level for blood lead is about 10 $\mu\text{g/dl}$.

A follow-up study, conducted by CDC and the State of Idaho, surveyed 364 children in 1983. Blood lead levels in the children from Smelterville ranged from 6 $\mu\text{g/dl}$ to 35 $\mu\text{g/dl}$, with a mean of 21 $\mu\text{g/dl}$. These levels dropped from an average of 68 $\mu\text{g/dl}$ in 1974 to 31 $\mu\text{g/dl}$ in 1980. In a second study area (Kellogg, Wardner, and Page residences), mean blood lead levels dropped from 49 $\mu\text{g/dl}$ in 1974 to 26 $\mu\text{g/dl}$ in 1980 and to 17 $\mu\text{g/dl}$ in 1983. Strong correlations were found with residential area soil lead levels, household dust lead levels, and (to a lesser extent) childhood mouthing behavior and other factors.

In 1983, when the Remedial Investigation/Feasibility Study (RI/FS) was started, and as a result of the blood lead studies, EPA decided to focus on the removal of contaminated soils from public areas in the populated portions of the site to reduce the lead poisoning in young children.

In 1985, a follow-up survey to the 1983 study was initiated. This was completed for CDC and involved 348 children. Of the 348, 10 children were identified as having blood lead levels exceeding the CDC's limit of 25 $\mu\text{g}/\text{dl}$, which represents a significant reduction from the previous studies. However, within this study, the highest blood-lead level in the area since 1979 was measured at 59 $\mu\text{g}/\text{dl}$ in a four-year-old child.

Most recently, in August 1989, the yearly Blood Lead Screening Program in the area identified eight children with elevated blood lead levels. Lead is of concern because it can cause nerve and kidney damage and young children are especially susceptible.

The exposure pathways directly reaching humans are from household dusts, soils, and garden vegetables. In 1974, the residential mean lead levels were 11,920 ppm for household dust, 7,224 for soils, and 231 ppm for garden lettuce (for residences within one mile of the smelter complex). In 1983, household dust lead levels averaged 3,994 ppm, soils averaged 3,504 ppm, and lettuce contained 48 ppm. Cadmium levels in 1974 were 63 ppm in soils and 28 ppm in lettuce (household dust not analyzed). In 1983, the levels were 54 ppm in soils, 5 ppm in lettuce, and 67 ppm in household dusts. For zinc, the 1974 levels were 2,340 ppm for soils (lettuce and dust were not analyzed) and the 1983 levels were 126 ppm for soils, 2,840 ppm for household dusts, and 73 ppm for lettuce. The population potentially at risk of exposure is relatively well known based on the blood, soil, household, and vegetative lead contents surveys.

In October 1989, an inspection of the smelter complex conducted by the Agency for Toxic Substances and Disease Registry resulted in a Public Health Advisory. The advisory concluded that the smelter complex was a "significant risk to public health."

Environmental and ecological damage has occurred in addition to health threats. The hillsides around the smelter complex are denuded of vegetation because of the smelter emissions and mining activity, as well as logging, and forest fires. The Bunker Hill Company, as part of a revegetation effort beginning in the early 1970s, identified about 14,400 (of 18,000) acres that had been damaged by smelter emissions or mining.

Furthermore, there is no year-long resident population of fish inhabiting the river in or below the project area to the confluence of the South Fork and the mainstem of the Coeur d'Alene River. According to the Site Characterization Report, this is due to the heavy metal concentrations in the South Fork of the Coeur d'Alene River.

CHEROKEE COUNTY, CHEROKEE, KANSAS

Operating History

The first significant lead and zinc mine in Kansas was in the City of Galena, where ore was discovered in 1876. Sphalerite (zinc sulfide) and galena (lead sulfide) were the minerals that contained the lead and zinc ore. Pyrite and marcasite (both iron disulfide) were commonly found in association with the lead and zinc minerals. The district was also an important source of cadmium, which was produced as a byproduct of lead-zinc smelting. A smelter was built along Short Creek in

the 1890s. The area near the original smelter was used for various smelting facilities until 1961, when the remaining facility was converted to produce sulfuric acid.

Lead and zinc ore in the Galena district is typically found in veins 80 to 100 feet below the surface, which permitted many small, shallow-depth mining operations to flourish. Exploration and mine development were accomplished by excavating vertical shafts using a modified room-and-pillar method to follow the ore vein. The use of vertical shafts as a means of mineral exploration and the subdivision of leases into small sublease mining plots result in a high density of mine shafts in the subsite. Several mines have collapsed, forming subsidence craters of varying sizes and shapes. Many circular subsidences are less than 75 feet in diameter, while others measure several hundred feet along the longest dimension. A ground level difference of 20 to 40 feet is common in the subsidences within the subsite, although some are filled with water and may be deeper.

Environmental Damages and Risks

Approximately 510 households outside of the City of Galena depend on private wells in the shallow ground water aquifer for their drinking water. These wells obtain water from the same geologic formation that had previously been mined. Sampling indicated that there is a potential that these wells may become contaminated with heavy metals.

Remedial Investigation and Operable Unit Feasibility Studies (OUFS) conducted by EPA show that mine wastes (and soils contaminated with mine wastes) also present a human health risk as a result of their incidental ingestion. Levels of exposure for lead, zinc, and cadmium, in particular, present a health risk.

ORONOGO-DUENWEG, JASPER COUNTY, MISSOURI

Operating History

Mining began in the area around 1850 and continued until the late 1960s. Between 1850 and 1950, the site generated over \$1 billion in revenues. Mining activities at the site involved retrieving crude ores from the mines to the surface, where the ores were milled into lead and zinc concentrates. Ore-bearing rock was crushed and ground into a fine gravel to liberate the desired materials. Waste products from the processing were removed and placed in large tailings piles. Barren rock containing no ore was also discarded in piles.

Environmental Damage and Risks

A Risk Assessment (RA) has not yet been performed for the site. However, public health implications of the site have been discussed in the U.S. Department of Health and Human Services' Preliminary Health Assessment for the site (PHA).

The most important human exposure pathways for the site are believed to be ingestion of contaminated ground water and surface water, inhalation of airborne contaminated dust particles, ingestion of contaminated soil by children in residential areas, and ingestion of contaminated aquatic organisms and of foodstuffs grown in contaminated soil. Dermal or mucous membrane contact is possible but unlikely.

Preliminary risk calculations indicate that excessive exposure to zinc, cadmium, and lead may be occurring for residents in the Oronogo-Duenweg Mining area. In addition, the State of Kansas has

conducted several health surveys indicating a high incidence of tuberculosis and lung cancer among area residents. Missouri has also started to examine lead levels in the blood of local individuals.

Surface water at the site, specifically Center Creek, is used for fishing. In addition, surface waters potentially affected by the site, including water contained in abandoned pits, may be used for crop irrigation, livestock watering, commercial purposes, and recreational purposes. Consequently, public health risks include the risk of exposure through the food chain.

Individuals in the small towns of the Oronogo-Duenweg area (Webb City, Oronogo, Duenweg, and Carterville) obtain their drinking water primarily from municipal wells screened in the deeper aquifer. Individuals living outside these towns, an estimated 1,500 people, obtain water from private wells tapping the shallow aquifer. Ground water samples collected in November 1988 contained concentrations of lead and cadmium that exceed EPA's proposed MCLs. A municipal water supply well located near the site was abandoned some time after 1972. The data for this well indicate that contamination of the deep aquifer with mine water may have occurred.

TAR CREEK, OTTAWA COUNTY, OKLAHOMA

Operating History

Lead-zinc ores were first discovered at the site in 1901, and the first mining output began in 1904. In 1914, the main body of ore was discovered, and mining activities increased substantially. Early mining was conducted by small operators on 40-acre tracts, but consolidation began in the 1930s. The mines were subject to flooding from inflows of ground water. The floods were controlled by the use of large capacity pumps during mining operations. Large-scale mining activities ceased in the mid-1960s, and the pumps were removed from the mines. By 1979, the majority of the underground mines were completely flooded. Acid mine water began to discharge via abandoned or partially plugged mine shaft openings and boreholes.

Environmental Damages and Risks

At locations both above and below the acid mine water discharge points, chronic water quality criteria for several heavy metals is exceeded. Heavy metal loadings increase downstream, while the pH decreases, resulting in severe stress to the aquatic community of Tar Creek. Studies found no fish and only a few benthic macroinvertebrates surviving in Tar Creek. The greatest threat to human health comes from dermal exposure to mine water from direct contact. Tar Creek is used for recreational purposes, including swimming.

The Roubidoux aquifer is still a safe drinking water supply. It serves a population of 21,000 in five principal communities, including Miami, Picher, Cardin, Quapaw, Commerce, and a few rural districts. Historical drinking water-quality data for community wells indicate no degradation to date, except in the city wells serving Quapaw, where two wells were abandoned because of mine water contamination. The contamination was attributed to either casing failure or migration of mine water from nearby abandoned wells.

The Neosho River, the Spring River, and Grand Lake, which receive water from Tar Creek, can be safely used as a raw water source for public water supplies, and fish samples indicate that the fish are safe for human consumption. Most of the heavy metals present in the acid mine water precipitate out of the water and into the Tar Creek and Neosho River stream sediments. This occurs primarily at the Tar Creek and Neosho River confluence, because the Neosho River has a flow capacity approximately

500 times greater than Tar Creek and a much greater buffering capacity. The Neosho River has received little impact from acid mine drainage into Tar Creek other than aesthetic alteration at the Tar Creek confluence. Air impacts were not evaluated.

SHARON STEEL/MIDVALE TAILINGS, MIDVALE, UTAH

Operating History

U.S. Smelting conducted milling and smelting operations at the site. The milling portion of the facility operated from 1910 to 1971. In 1971, UV Industries bought U.S. Smelting. The smelter, located to the north of 7800 South Street, is on the Midvale Slag Superfund site, and was closed in 1958. Sharon Steel acquired the mill and tailings site in 1979. The original operations involved receiving lead, copper, and zinc ores; extracting sulfide concentrates of these metals in the milling operation; and smelting these concentrates to extract the metals in purer form. The facility also operated as a custom mill, receiving ores and concentrating and extracting metals. The wastes from the milling operations were disposed of in unconsolidated tailings piles. The mill site includes several mill buildings and approximately 12 to 14 million cubic yards of tailings in uncovered piles.

In June 1982, wind-blown tailings were sampled and found to contain arsenic, cadmium, chromium, copper, lead, and zinc. A 6-foot chain link fence was erected by Sharon Steel along the northern boundary of the property to prevent direct contact with the tailings piles. The fence, however, did not prevent the tailings from blowing through and over the fence and down the embankment of a highway right-of-way. On September 17, 1982, the Utah State Bureau of Air Quality issued a request for a compliance plan to control the fugitive dust emanating from Sharon Steel. Sharon Steel Corporation responded to this request in October of that year with a proposal to use water flooding to suppress the dust. The State withdrew an initial approval of the plan and ordered that Sharon Steel design an alternative plan. Ultimately, a dust mitigation program using a chemical polymer dust suppressant was implemented in May and June 1988.

Also in 1988, a slope stabilization and river bank restoration plan was implemented. Where the berm bordering the site had been washed out by high river flows, it was reconstructed to serve as a buffer zone between the tailings and the river. Rehabilitation involved removing all tailings from the berm where it had been washed out. These tailings were placed on existing piles away from the river and embankments were sloped at a ratio of approximately 3:1 in a horizontal to vertical configuration. In addition, stream bank areas requiring repair were filled with gravel material, compacted, and covered with a graded rip rap. Debris and sediments that were directing river flow into the tailings side of the river were also removed and the river channel was "cleaned" so that river flow would be redirected away from the bank bordering the tailings.

Environmental Damages and Risks

An environmental health problem was first suspected in June 1982 when the Utah State Department of Health was notified that citizens were gathering wind-blown tailings for sandboxes and gardens. Sand and wind-blown tailings were sampled by the State. Arsenic, cadmium, chromium, copper, lead, and zinc were found.

The City of Midvale, less than one mile away, has a population of 12,085 and within two miles of the site there are 43,911 people. The Jordan River is classified for recreational use, excluding swimming, cold water game fishing, and agriculture.

Contaminants of concern in the mill tailings are aluminum, antimony, arsenic, cadmium, chromium, copper, lead, manganese, silver, thallium, and zinc. Arsenic, cadmium, and lead are likely to be of greatest potential concern to human health as discovered in the endangerment assessment performed as part of the RI.

The exposure pathways evaluated under current and potential future use conditions are:

- Direct ingestion of site tailings or contaminated surface soils
- Ingestion of contaminated ground water
- Inhalation of tailings contaminated dust
- Ingestion of home-grown produce by nearby residents

For all the exposure pathways evaluated under current use in the baseline risk assessment, arsenic is carcinogenic, and arsenic and cadmium are carcinogenic through inhalation. The excess upper-bound lifetime cancer risks for all exposure pathways combined is 5×10^{-4} , primarily from exposure to arsenic from ingestion of tailings in sandboxes and ingestion of indoor dust. However, "public information efforts by the State of Utah and the Environmental Protection Agency have generally eliminated the route of exposure involving tailings ingestion from sandboxes." Noncarcinogenic effects can also result from exposure to arsenic and cadmium through the pathways evaluated.

The overall excess upperbound cancer risk for exposure pathways under future use conditions is 1×10^{-3} (chance in 1,000), resulting primarily from arsenic through indoor dust ingestion and tailings ingestion. Noncarcinogenic adverse effects could also occur because of exposure to arsenic and cadmium. Of greatest concern is the ingestion of lead from the tailings study area that can cause noncarcinogenic adverse effects.

Potential threats to environmental receptors include vegetation, aquatic life, and wildlife. The geometric mean contamination level of lead in residential soils was found to be 722 milligrams per kilogram (mg/kg) (ppm). Aquatic life can be exposed to contaminants both in surface water and sediments. Of greatest concern are the high levels of metals in the sediments, which may act as a reservoir that can supply metals to the water column or be directly consumed by benthic organisms. Wildlife in the wetlands may be exposed to site-related contaminants through direct contact with surface waters or sediments or through the food chain. Among the metals present at the study area, lead has been shown to bioconcentrate in insects, small mammals, and songbirds, which may then be consumed by larger animals. While the potential of adverse effects due to lead exposure exists, it is presently unknown whether wildlife is being adversely affected by the metals found in the study area.

APPENDIX 1-C
SUMMARY OF COMMENTS AND EPA RESPONSES

Comments on the Draft Industry Profile and EPA Responses

A copy of the draft *Mining Industry Profile: Lead-Zinc* was provided to the following for their review and comment: the U.S. Department of the Interior, the Bureau of Mines, the Western Governors' Association, the Interstate Mining Compact Commission, and the American Mining Congress (AMC), and Public Interest Groups. The comments included technical and editorial changes, as well as comments on the scope of the profile and its relationship to the authorities provided under RCRA Subtitle D.

Because several general concerns were raised by a number of commenters, EPA has grouped the comments into two categories. The first category includes seven general concerns that were raised by all commenters. These concerns are addressed in the first section below. The second category consists of technical comments on the profile that were raised by only one reviewer as opposed to the group as a whole. These are addressed in the second section below. All other comments, including minor technical and marginal notes, have been incorporated into the revised profile. EPA believes these comments have improved the document's accuracy and clarity and would like to thank all the agencies, companies, and individuals for their time and effort.

General Issues Pertaining to All Profiles

1. **Comment:** Several commenters objected to the use of hypothetical phrases like "may cause" or "may occur." Their use was characterized as misleading and inappropriate in describing environmental impacts in an industry profile of this type.

Response: We believe the descriptions of conditions and impacts that may occur regarding potential effects is appropriate in many cases since the intent of the relevant sections of the profiles is to describe potential impacts that may occur as a result of extracting and beneficiating ores and minerals. As noted in the responses to related comments (see below), EPA has extensively revised the sections of the profiles addressing environmental effects. Such sections are now more focused and direct and describe, in general terms, a number of specific types of impacts that can occur under particular conditions or in particular environments.

2. **Comment:** A related issue raised by commenters was that EPA did not balance the profiles by describing environmental protection practices currently followed by the mining industry. Instead, the commenters were critical that EPA selected the worst sites to describe and these sites represent only a small number of mines and even a few clandestine operations.

Response: We believe the profiles represent current environmental management practices as described in the current literature.

3. **Comment:** Commenters on the profiles were concerned that the sites described in the discussion of environmental effects were under some other regulatory authority (e.g., CERCLA).

Response: As noted above, the relevant sections of the profile have been revised extensively. However, we believe, with proper qualification, sites under other regulatory authorities, including CERCLA, are relevant to any examination of actual or potential environmental effects.

4. Comment: Commenters were concerned the profiles addressed materials other than those considered "wastes" under RCRA.

Response: The profile has been edited so that only RCRA defined wastes are discussed.

5. Comment: Many commenters recommended a discussion of the mitigating effects of site-specific factors on potential environmental effects.

Response: As noted above, EPA has revised the relevant sections of the profiles, including the addition of language that emphasizes the site-specific nature of potential environmental effects.

6. Comment: Many commenters recommended that the effectiveness of State regulatory actions in preventing adverse environmental effects be integrated into any discussion of potential effects.

Response: The profiles have been amended to reflect the fact that State requirements can substantially reduce or eliminate many adverse environmental effects.

7. Comment: A number of comments were received on the table in each draft profile that cited NIOSH data on the quantities of certain chemicals found on mine property and that included worker exposure limits. Commenters questioned the data's accuracy and relevance.

Response: The table has been replaced with a simple list of chemicals typically found on sites.

Technical Issues Specific to the Lead-Zinc Profile

8. Comment: Discussion of processing activities such as smelters and stack emissions should be deleted.

Response: EPA has revised the profile to address only extraction and beneficiation. It should be noted that a description of sintering, as it applies to lead and zinc concentrates, remains in the text since it is a step in beneficiation.

9. Comment: Add information on the Van Stone Mine to Table 1 (Bureau of Mines).

Response: According to sources used for this table, the Van Stone Mine is located in Canada and therefore was not included.

10. Comment: In Appendix B, concerning the discussion of Clear Creek on the National Priorities List, verify that there is a health risk for inhalation of these materials (Hecla Mining Company).

Response: The Record of Decision clearly stated that a low risk to health may exist at the site.

APPENDIX 1-D

ACRONYMS

ACRONYMS

ADF&G	Alaska Department of Fish and Game
AMD	Acid Mine Drainage
ANFO	Ammonium Nitrate Fertilizer and Fuel Oil
ASARCO	American Smelting and Refining Company
ATSDR	Agency for Toxic Substances and Disease Registry
AWQC	Ambient Water Quality Criteria
BAT	Best Available Technology
BLM	U.S. Bureau of Land Management
BPJ	Best Professional Judgment
BPT	Best Practicable Technology
BRA	Baseline Risk Assessment
CAA	Clean Air Act
CDC	Centers for Disease Control
CFR	Code of Federal Regulations
CWA	Clean Water Act
DEC	Department of Environmental Conservation
dscm	Dry Standard Cubic Meter
DNR	Department of Natural Resources
EA	Endangerment Assessment
EP	Extraction Procedure
EPA	U.S. Environmental Protection Agency
FLPMA	Federal Land Policy and Management Act
FS	U.S. Forest Service
FWS	U.S. Fish and Wildlife Service
gpm	gallons per minute
HSWA	Hazardous and Solid Waste Amendments
ICS	Individual Control Strategy
ISP	Imperial Smelting Process
LDH	Load-Dump-Haul
MCL	Maximum Contaminant Level
mm	millimeters
MMWM	Metallic Minerals Waste Management
MMWMA	Metallic Minerals Waste Management Act
MSHA	Mine Safety and Health Administration
NAAQS	National Ambient Air Quality Standards
NEPA	National Environmental Policy Act
NESHAP	National Emission Standards for Hazardous Air Pollutants
NIOSH	National Institute for Occupational Safety and Health
NPL	National Priorities List
NPDES	National Pollutant Discharge Elimination System
NPS	National Park Service
NSPS	New Source Performance Standards
OUFS	Operable Unit Feasibility Studies
PEL	Permissible Exposure Limit
PHA	Preliminary Health Assessment
ppm	parts per million
PRP	Potentially Responsible Parties

ACRONYMS (Continued)

PSD	Prevention of Significant Deterioration
RA	Risk Assessment
RCRA	Resource Conservation and Recovery Act
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
ROD	Record of Decision
SDWA	Safe Drinking Water Act
SIC	Standard Industrial Category
SIP	State Implementation Plan
st	Short Tons
SWDA	Solid Waste Disposal Act
TSCA	Toxic Substances Control Act
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
ug/g	micrograms per gram
ug/L	micrograms per liter
ug/m ³	micrograms per cubic meter
U.S.	United States
USDA	U.S. Department of Agriculture
WHO	World Health Organization

MINE SITE VISIT:
DOE RUN FLETCHER MINE AND MILL

**U.S. Environmental Protection Agency
Office of Solid Waste
401 M Street SW
Washington, DC 20460**

2.0 SITE VISIT REPORT: DOE RUN FLETCHER

2.1 INTRODUCTION

2.1.1 Background

The U.S. Environmental Protection Agency (EPA) is assisting states to improve their mining programs. As part of this ongoing effort, EPA is gathering data related to waste generation and management practices by conducting visits to mine sites. As one of several site visits, EPA visited the Doe Run Fletcher Mine and Mill on September 24 and 25, 1991.

Sites to be visited were selected by EPA to represent both an array of mining industry sectors and different regional geographies. All site visits have been conducted pursuant to RCRA Sections 3001 and 3007 information collection authorities. When sites have been on Federal land, EPA has invited representatives of the land management agencies (Bureau of Land Management and the Forest Service). State agency representatives and EPA regional personnel have also been invited to participate in each site visit.

For each site, EPA has collected information using a three-step approach: (1) contacting the facility by telephone to obtain initial information, (2) contacting state regulatory agencies by telephone to get further information, and (3) conducting the actual site visit. Information collected prior to the visit was then reviewed during the site visit.

In preparing this report, EPA collected information from a variety of sources, including The Doe Run Company and the State of Missouri Department of Natural Resources (DNR) Water Quality Division. Additional information was collected during telephone conversations, the site visit, and from other published sources. The following individuals participated in the site visit to the Doe Run Fletcher Mine and Mill facility on September 24 and 25, 1991:

Doe Run

John Carter, Environmental Manager	314-244-8152
Terry Perkins, Mills and Metallurgy Manager	314-244-8612
John Fitzsimmons, VP Mining Doe Run, General Manager of SEMO Operations	314-244-8110
Bill Tierney, Mines Manager	314-244-8150
Denis Murphy, Environmental Quality Control Specialist	314-244-8104
Bill Mount, Assistant General Manager	314-244-8112
Quentin Schmidt, Quality Control Manager	314-244-8105
Dan Vornberg, Environmental Manager	314-933-3143
Walter Nowotny, General Counsel	314-991-7150

Missouri Department of Natural Resources

Jim Burris, Division of Environmental Quality

314-785-0832

Bureau of Land Management

Bibi Booth, Hazardous Materials Coordinator

703-461-1334

Jeff Carroll, Wildlife Management Biologist, Rolla Office

314-364-0203

Forest Service

Lynn McClure, Forester

314-729-5532

Richard Sibley, Appraiser

314-364-4621

EPA

Steve Hoffman, Chief, Mine Waste Section,
Office of Solid Waste

703-308-8421

Ron Ritter, Region VII

913-551-7005

Carl Blomgren, Region VII

913-551-7680

Science Applications International Corporation

Ingrid Rosencrantz, Environmental Scientist

703-734-2508

Joseph Rissing, Geologist

703-734-4366

Participants in the site visit were provided an opportunity to comment on a draft of this report.

Comments were submitted by The Doe Run Company, the Bureau of Land Management (BLM), and the Forest Service. Doe Run Company comments and EPA's responses are presented in Appendix A. BLM and Forest Service comments and EPA responses are presented in Appendices B and C, respectively.

2.1.2 General Description

The Fletcher facility is located approximately 80 miles south-southwest of St. Louis, and 25 miles south of Viburnum, Missouri, in Reynolds County (Figure 2-1). The Doe Run Company also operates 5 additional mines and 3 mills on the Viburnum Trend, part of the New Lead Belt. The Fletcher operation was built and operated by the St. Joe Minerals Corporation between 1965 and 1981. The Fluor Corporation purchased St. Joe in 1981. Doe Run was formed in 1986 when St. Joe and Homestake Mining Company combined their lead-zinc-copper assets in Missouri in a general partnership. In 1990, Fluor purchased all of Homestake's interests, making Doe Run a wholly owned subsidiary corporation of the Fluor Corporation.

The Fletcher mine and mill extract and beneficiate a dolomitic lead-zinc-copper ore typical of those deposits found on the Viburnum Trend. The Fletcher surface facilities are approximately 1180 feet above sea level. The mine workings are located between 1000 and 1120 feet below ground. Access to the mine is by two 12.5 foot diameter shafts located about 100 feet apart. Construction of the shafts was completed in 1965.

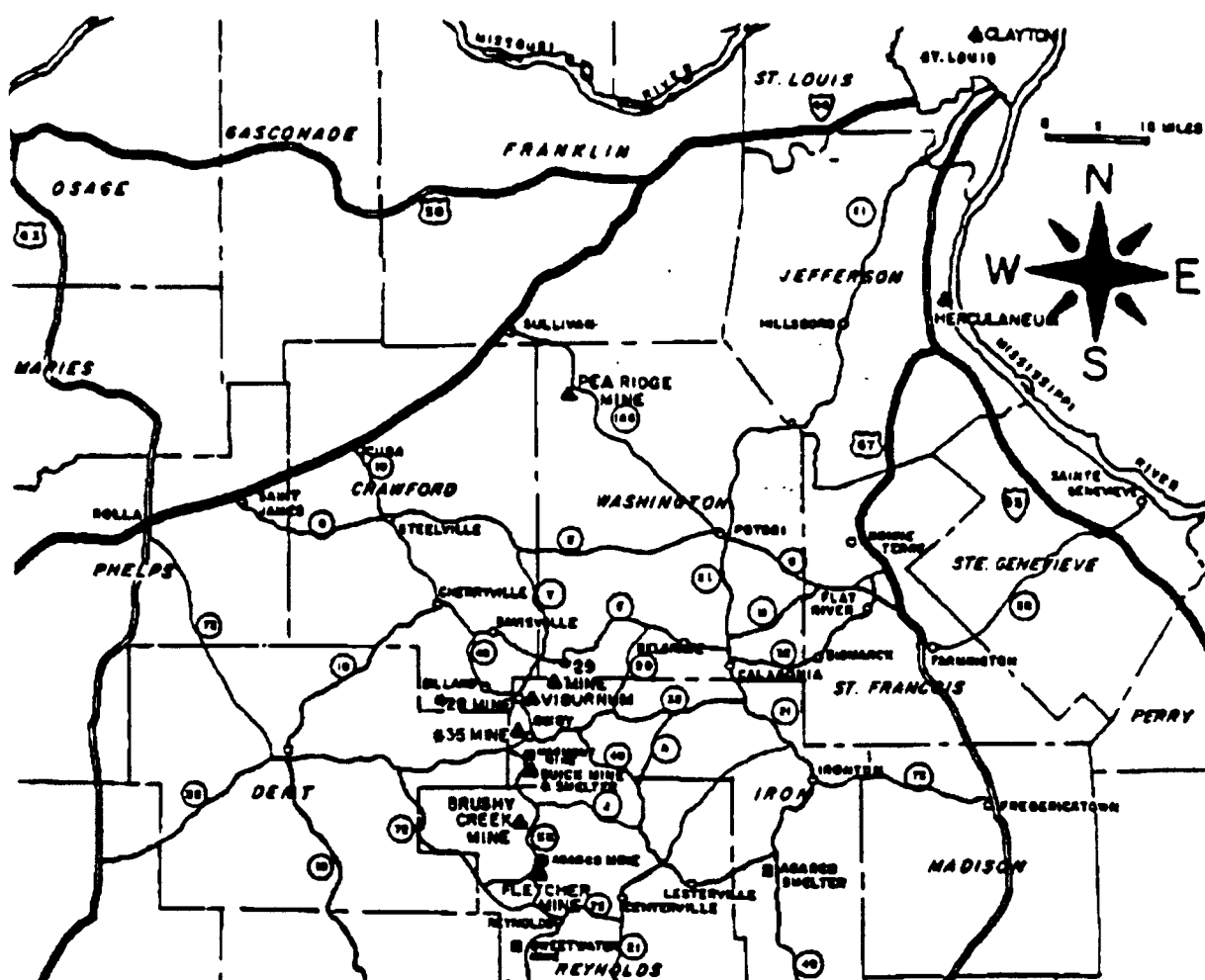


Figure 2-1. Area of South East Missouri

Shaft Number 30 is the deepest, extending 1344 feet below the surface; it is used to lift ore to the surface and supply air to the mine. Shaft Number 31 provides access for men and materials to the mine. The mine is an open stope room and pillar design; rooms are 32 feet square, pillars are 28 feet square. Mine production capacity is 6000 wet tons per day, 5 days per week. Current projections are that mining operations will end in 2005 and that 44 million tons of ore will have been removed. The mill began operation early in 1967 producing lead, zinc, and copper concentrates using standard flotation methods. Mill capacity is 5000 tons per day, 6 days per week. Lead concentrates are transported to smelters in Herculaneum, Missouri, zinc concentrates are sent to Sauget, Illinois and Bartlesville, Oklahoma. Most copper concentrates are trucked to Bussen Quarry in Missouri where they are stored before being shipped overseas.

Surface facilities occupy approximately 320 acres owned by The Doe Run Company. The Company holds approximately 2000 acres of surface rights in the area and a large area of leased mineral rights on public land (Figure 2-2). As part of their application required by Missouri's new Metallic Minerals Waste Management Act, which became law on August 28, 1989, the Company submitted a map indicating property rights as of February 1990. Doe Run holds surface and/or mineral rights for contiguous portions of Sections 13, 14, 23, 24, and 25, Tier 32 North, Range 2 West, and Sections 18, 19, 29, 30, and 31, Tier 32 North, Range 1 West (Doe Run, Feb, 1990). As part of the Fletcher Development Contract between the Doe Run Company and the United States of America, an additional 3,845.65 acres of public land in the Mark Twain National Forest are leased to Doe Run by the Bureau of Land Management (BLM) through 2 separate leases. Lands held by other persons total 339 acres. Doe Run estimates that 60 percent of Fletcher production comes from National Forest Land. As of 1981 a total of 6,319.65 acres of leased and owned surface and/or mineral rights were held by the Doe Run Fletcher Division (USGS, Vol. II, 1981). In 1986, the Fletcher Division held 9,102 acres of mineral rights, owned or leased, in addition to the area occupied by the surface facilities. Doe Run also holds a prospecting permit (ES-035967) for 2376.66 acres in Reynolds County. This permit was originally issued to Homestake Lead Company of Missouri in November 1986 for a two year period; it was to be reissued in November 1991 for another 4 years (BLM letter, 1991).

2.1.3 Environmental Setting

The Fletcher facility is located on the Ozark Plateau in Southeastern Missouri and is surrounded by the Salem-Potosi Ranger District of Mark Twain National Forest. This area is in the USGS seismic zone III. The immediate site is bordered on all sides by dense oak-hickory and oak-pine forests, and maples and sycamores are prevalent. There are no private residences in the immediate vicinity of the mill or tailings impoundment, however, a few private residences are located along the Bee Fork, downstream from the tailings dam. These residents use shallow wells or surface water sources such as springs for drinking water. The primary economic activity in the area, other than mining, is logging (Allgood, 1979).

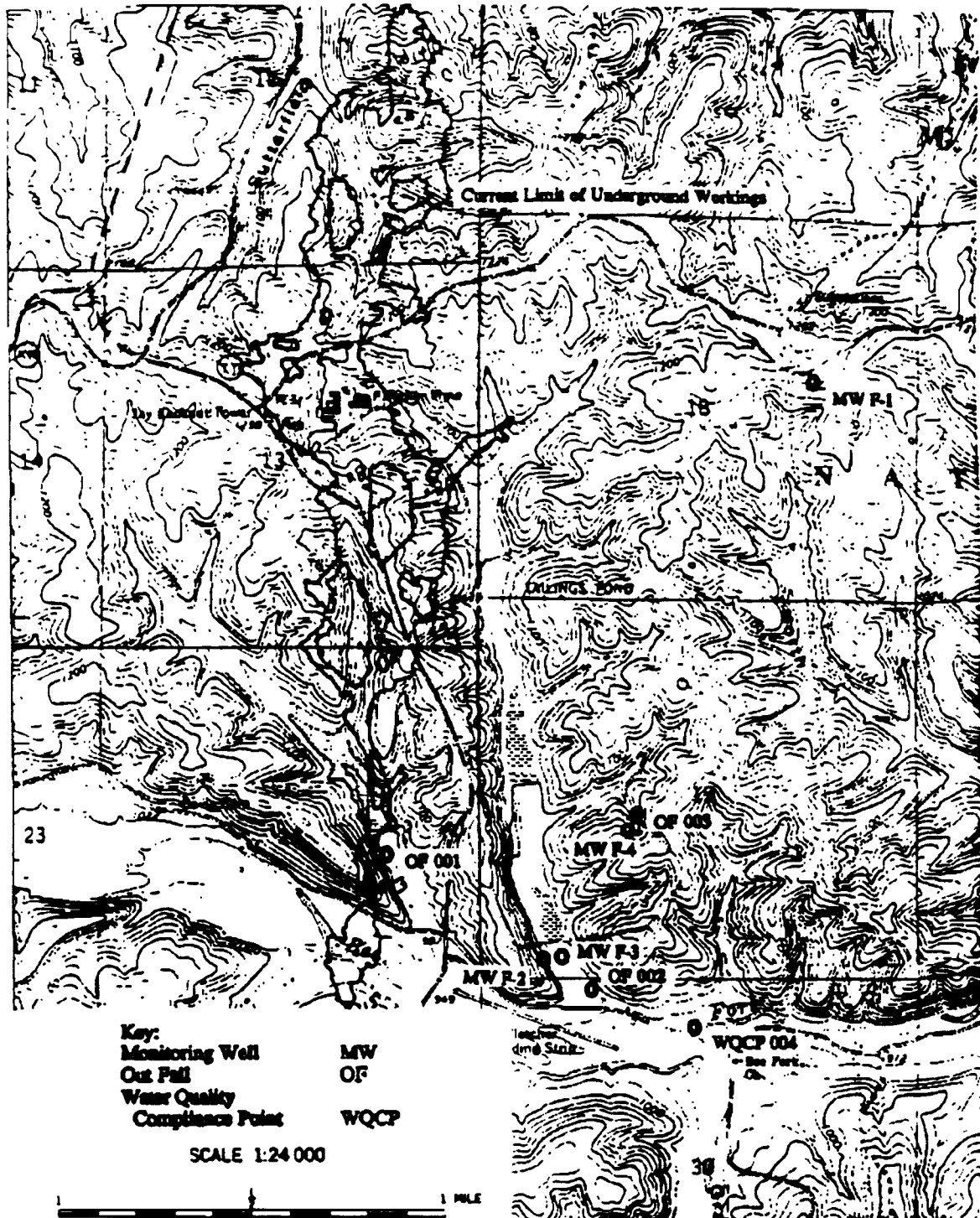


Figure 2-2. Topographic Map of the Site Area (modified)

The landscape is a highly weathered surface, dating to circa 500 million years before present. Slope angles in the region vary from 7 to 40 percent. The Missouri General Soil Map classifies soils in the region as alfisols and ultisols. Local soils are characterized as having clay horizons with chert, and low base saturation. Soil thickness in the region varies from 4 to 50 feet thick. Karst features are present and affect the surface hydrology.

According to information presented during the site visit, there are no threatened or endangered animals or plants in the immediate area, however, it was noted during the visit that some birds of prey winter over in the vicinity. Grasshopper Hollow is located south of the Fletcher tailings dam across Bee Fork. The Nature Conservancy believes that the area is a critical wetland. Doe Run owns the surface and mineral rights for the lower reaches of the Hollow and the mineral rights for most of the upper reaches. The Company has given the Nature Conservancy a lease to manage the surface for conservancy purposes. Comments received from EPA Region VII indicate that the Hollow is within or near the range of the Grey Bat (*Myotis Soditos*), which is an endangered species.

2.1.3.1 Climate

Southeast Missouri is dominated by both dry continental air masses from the western plains and humid tropical air from the Gulf of Mexico. The average annual temperature and precipitation in Reynolds County is 60° F and 44 inches, respectively. The average annual runoff is 16 inches. Roughly 40 percent of the precipitation falls from May through August in the form of thunderstorms. At times these storms generate more than 10 inches of rainfall in a 24 hour period. Up to 12 inches of snowfall can be expected annually (Mineral and Water Resources of Missouri, 1967).

2.1.3.2 Geology

Deposits of base metal ores occur in Cambrian age sedimentary rocks surrounding a dome of Precambrian rocks that form the St. Francois Mountains. The sedimentary rocks are thought to have formed reefs around the Precambrian dome. Mineralization occurs throughout the sedimentary deposits and includes lead, zinc, copper, nickel, cobalt, and silver metals. In a typical section, the Lamotte Sandstone lies unconformably above the Precambrian rocks, pinching out against the dome (Figure 2-3). The Bonneterre Formation is conformable with the Lamotte Sandstone, and is the lowest carbonate rock formation in the region. Originally deposited as a limestone, it was most likely dolomitized during or soon after lithification. It is theorized that base metals were deposited by migrating hydrothermal solutions in the Bonneterre Formation. The Bonneterre hosts the richest lead ore in the sequence (Mineral and Water Resources of Missouri, 1967; USGS, Vol. II, 1984).

The Davis Formation overlies the Bonneterre and consists of interbedded shales, carbonates, siltstones, sandstones, and conglomerates. These sediments are less permeable than the underlying formations and may have acted as a cap on the reservoir. Other Cambrian formations, in ascending order through the section, include the Derby-Doerun, Potosi, Eminence, and Gasconade dolomites.

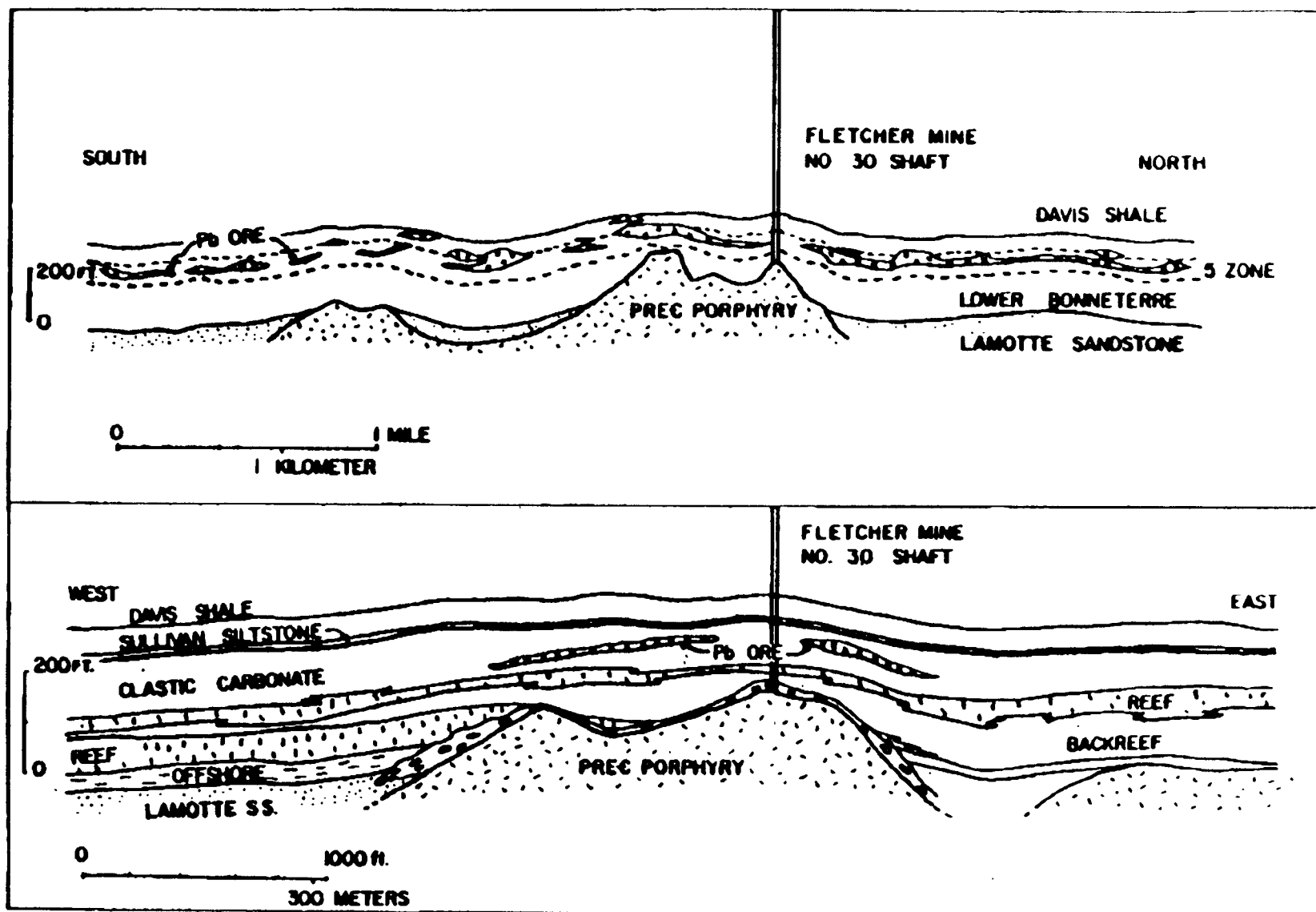


Figure 2-3. Cross-section of Geology From USGS Reports

(Source: USGS, Vol. II 1981)

The average thickness of these units above the Bonneterre formation is 800 feet (Hydro-Search, 1990; USGS, Vol. II, 1984).

At the Fletcher mine the Bonneterre Formation is approximately 150 feet thick. Different facies observed in the mine include offshore deposits, algal stromatolites, back reef carbonates, reef complexes, off-reef sands, and shelf carbonates. These are characteristic of a barrier reef system associated with the St. Francois Mountains. Both the mines in the Old Lead Belt, located northeast of the St. Francois Mountains, and those in the New Lead Belt, or Viburnum trend, are centered on these reef deposits (USGS, Vol. II, 1984).

The Fletcher mine is located in the southern portion of the Viburnum trend. The trend extends 30 miles north to south and is located on the western flank of the St. Francois Mountains which lie 40 miles to the east. The richest mineral bearing zone of the Bonneterre Formation in the Fletcher mine is composed of porous, thick-bedded oolitic dolomite. Mineralization at Fletcher extends 5 miles north to south. The northern end contains the richest ore, mineralization is up to 1000 feet wide and averages 20 feet thick. To the south, the ore body narrows to 200 feet and the grade diminishes (USGS, Vol. II, 1984; MMWMA, 1990).

The average concentration of values in the Fletcher mine ore is: galena (5.5%), sphalerite (1.0%), and chalcopyrite (0.3%). Gangue minerals are calcite, dolomite, pyrite, and marcasite. Galena occurs as open-space filling in banded disseminations and as thin seams along bedding planes. Sphalerite also occurs as banded disseminations, usually in association with high-grade galena mineralization. In the typical hand specimen, fine grain sphalerite is difficult to distinguish from the brown color of the dolomites. Chalcopyrite occurs as thin bands at the base of galena mineralization, but may form as crystals in open-space fillings.

2.1.3.3 Hydrology

Surface and subsurface hydrology in the region are controlled by karst formations in the carbonate system. Information concerning the regional groundwater is limited and therefore not well understood. Two primary aquifers are identified in the profile below the Fletcher facility. The upper aquifer is located in the Derby-Doerun, Potosi, Eminence, and Gasconade dolomites, extending to 800 feet below the surface. Flow in this aquifer is probably controlled by local topography. Wells in this unit may yield between 50 and 600 gallons per minute (gpm). The lower aquifer is in the Bonneterre-Lamotte Formations, found at depths greater than 1000 feet below the surface. Flow in this aquifer is controlled by regional gradients of the Ozark Plateau. This aquifer may yield between 10 and 100 gpm. These aquifers are separated by the shales of the Davis Formation, which forms an aquitard (Hydro-Search, 1990).

Water chemistry of the upper aquifer (Potosi Formation) taken from the northern end of the Viburnum trend indicate a calcium-magnesium-bicarbonate type water having a total dissolved solids (TDS) concentration of 250 mg/l. Base metal concentrations are low, with only zinc showing a concentration of 0.1 mg/l.

Surface water in the vicinity of the Fletcher mine drains south to the Bee Fork. This part of the Black River drainage basin drains most of the Viburnum trend. Bee Fork is typical of upland Ozark streams, with a TDS of 62 mg/l, less than 1 mg/l suspended solids, and hardness of 43 CaCO₃ equivalents. The mill facility and tailings impoundment are located in the West Fork Hollow. Its upper reaches drain into the Fletcher tailing impoundment. The mine water pond is located in the unnamed Hollow west of West Fork hollow. Streams in these watersheds flow intermittently and are described as wet weather creeks. A report by Hydro-Search stated that streams in West Fork Hollow and the mine water pond watersheds are "water losers," since most of the surface water is lost to bedrock in the karst terrain (Hydro-Search, 1990).

2.2 FACILITY OPERATION

During the first half of the 1980's, depressed metal prices and labor disputes hampered operations throughout the New Lead Belt. When the Doe Run Company was formed in 1986, the Fletcher mine and mill were closed. Doe Run re-opened the Fletcher facility in 1987 with a 3 year plan to update the mill facility and improve process control. Work included an updating of the mill building structure, new tailings and mill water return pipelines were installed, and the crusher was overhauled. Recovery rates are 97 percent for lead and 80 percent for zinc.

The Fletcher mine/mill surface complex covers approximately 20 acres excluding the tailings pond. Support facilities are located inside a fenced yard. The 2 primary structures are the service and concentrator buildings. The service building houses the offices, boiler room, hoist room, control room, eating room, locker facilities, and the surface supply house. The concentrator building is 3 stories high and houses the mill equipment from the secondary crusher through final concentrates including the ball and rod mills and flotation cells. Individual rooms include the console room, sample analysis room, and offices. The reagent storage room is on the second floor of the concentrator building, above the main floor, and contains a 6,200 gallon tank of mixed alcohol (frothing agent), a 6,155 gallon tank of ammoniated cupric chloride (CuNH_4Cl , activator for sphalerite), and two 4,100 gallon tanks of zinc sulfate (depressant for sphalerite). Dry reagents are also stored in bags and closed drums depending on the amount used; these include starch (depressant for copper flotation), caustic soda (used with starch), xanthate (primary collector for galena and sphalerite), sodium cyanide (depressant for iron sulfides), sodium dichromate (lead depressant in copper and zinc circuits), and sodium dioctyl sulfosuccinate (filter aid).

Separate from these buildings are tanks containing: No. 1 and 2 fuel oil (5 tanks, total 40,500 gal.), sulfur dioxide (10,000 gal., for pH regulation in copper flotation), liquid petroleum gas (2x30,000 gal.), hydraulic oil (3 tanks, total 12,500 gal.), and unleaded gasoline (2000 gal.). Most of these tanks have containment walls around them. According to the March 1991 Emissions Inventory Questionnaire (EIQ) all tanks are fitted with fixed roofs. Lubricating oil is stored on the surface in drums under a roof. Detonator caps and explosives are stored underground. A 2 million gallon asphalt lined mill water reservoir is located 100 feet above and 450 feet west of the service building.

Automation is an important factor in process control at the Fletcher mill. Automatic grinding control and level-sensing devices installed on the flotation cells control the flow through the mill. A Courier 30 On-stream X-Ray Analyzer and Proscon Process Control and Management System was installed in 1989. The X-Ray Analyzer is used to assay 6 process streams including: feed to the flotation cells, final lead, zinc, and copper concentrates, and tails. Data generated are in percent concentration of lead, zinc, copper, and iron. The Process Control and Management System has helped to stabilize Doe Run's mill process and improved recoveries (Jones, 1991). Additional information on this system is presented in Section 2.2, Mill Operation under Process Control.

As part of their pollution prevention effort following the re-opening of the Fletcher facility in 1987, Doe Run is participating in EPA's 33/50 Program. This is a voluntary pollution prevention program to reduce releases and off-site transfers of 17 toxic chemicals by 33 percent by the end of 1992, and by 50 percent by the end of 1995. Changes in metallurgy and automation produced a 6 percent increase in concentrate quality at the mill, thereby reducing smelter slag volume and containment content.

2.2.1 Mining Operations

The mine is centered around the shafts, extending more than 1 mile north of the shaft and 1.5 miles south (Figure 2-2). Vertically, the mine uses 2 main levels (Figure 2-4). The upper level is the main mining level and location of the underground offices, storage areas, and maintenance shops. The mine employs 65 people underground. Blasting material (ammonium nitrate and fuel oil (ANFO) and dynamite), diesel fuel (5,000 gallon tank), hydraulic oil (55 gallon drums), and lubricants are stored underground. All the underground equipment is diesel powered. The shop consists of 3 bays for performing all vehicle and equipment maintenance. Mine wall surface areas near the shops and office areas are painted with Bondex and latex every 3 to 5 years to reflect more light. Fletcher receives explosives from deliveries by the distributor on rounds to Doe Run operations. The lower level covers a smaller area and is the location for the sumps used to remove mine water and the underground ventilation system.

Mine water is pumped from the mine at a rate of 3,000 to 3,750 gpm. Water collects in 3 large sumps, one each located at the north, central, and south ends of the mine. The largest sump is 200 feet wide, 300 feet long and 30 feet deep. According to Doe Run personnel, an oil skimmer is used at each sump to remove any waste oil from the surface of the sumps; at the time of the visit, all 3 sumps were working. Seven large turbine pumps remove water from the mine through a pipe in shaft number 30. Small amounts of mine water are used for drilling and dust control for the jaw crusher and are supplied throughout the mine in a 2 inch pipe.

Ventilation is supplied by six 5 foot diameter air shafts. Two are located at the north end, two near the main shafts and two at the south end of the mine. The shafts supply air to the upper and lower mine levels. Air is pulled into the mine using Joy Axivane fans. Mine air is exhausted out shaft number 30. Air flows through the mine at a rate of 240,000 cubic feet per minute (USGS, Vol. II, 1981).

The Fletcher mine uses an open stope room and pillar design to extract the ore. Current ore production capacity is 6000 wet tons per day, or about 1.44 million tons per year. The mine operates 5 days per week, using 2 shifts each day for production (blasting and hauling) and maintenance and 3 shifts to hoist the ore to the surface. An even pillar pattern is maintained and each pillar is 28 feet square and 32 feet apart. The height of the mine opening is determined by the ore thickness.

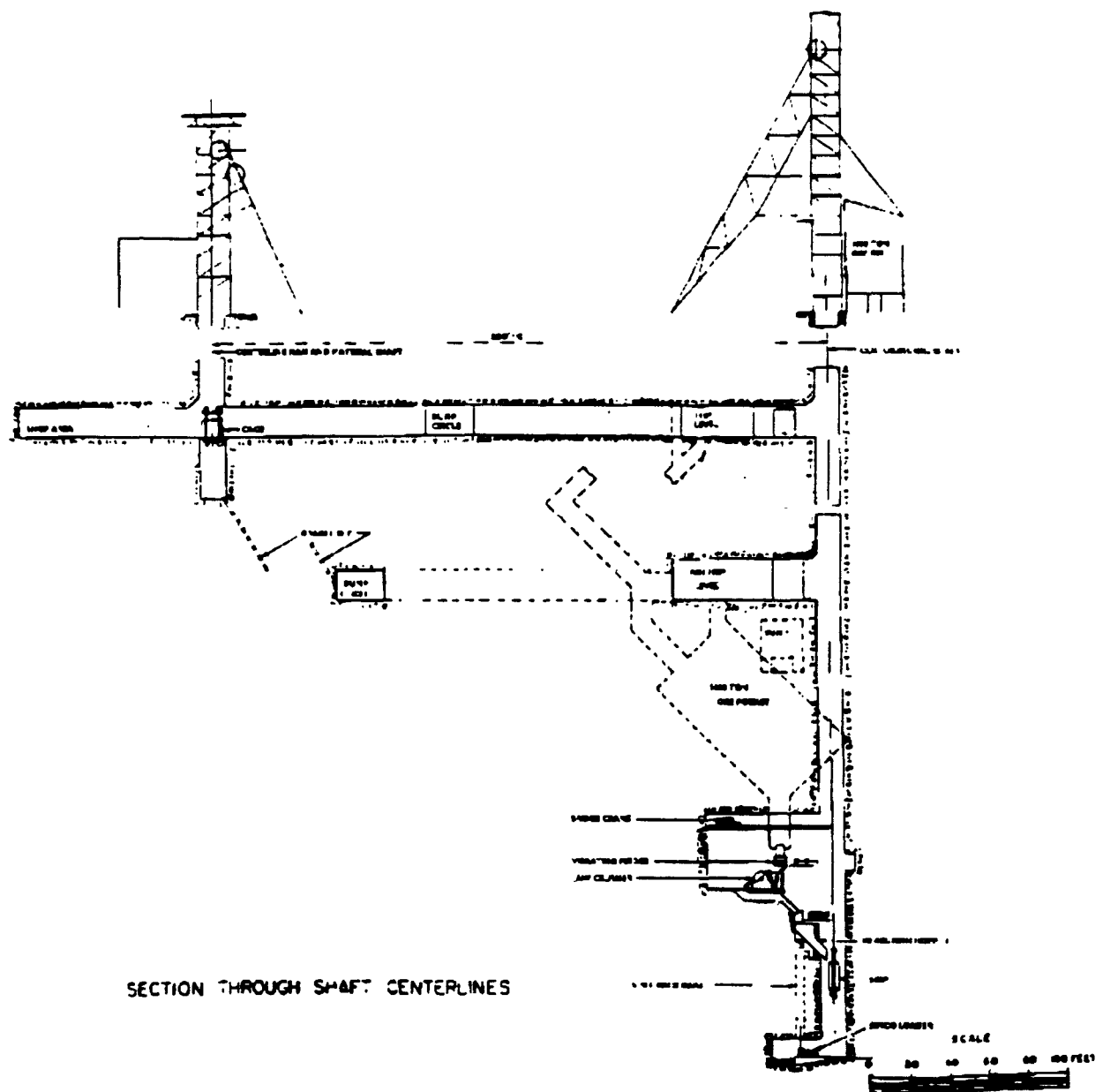


Figure 2-4. Cross Section of Shafts and Mine

(Source: USGS, Vol. II 1981)

Ore is removed by drilling and blasting. Truck mounted hydraulic drills are used to drill holes for placing explosives. The Fletcher mine uses both ANFO and dynamite. The choice of which explosive to use is determined by whether the holes are wet or dry; when holes are wet, dynamite is used. Fletcher uses approximately 80 % ANFO; 20 % dynamite. A charging tractor is used to place the explosives. Typically, with each mining pass (blasting), 18 - 20 vertical feet of material is removed across a 32 foot wall to a depth of 11 feet. An average round breaks 600 tons of rock. In the first pass the upper ore zone is removed; if ore grade material remains in the roof after the first pass, the ore removed can be used as a platform for additional drilling and blasting of the roof. Subsequent downward passes remove the bottom until the lower limit of the ore body is reached. The typical ore thickness at Fletcher can be as much as 110 feet, with an extraction ratio of 78 to 80 percent. At the end of mining activity, it is possible that some of the high-grade pillars may be removed.

Each drilling and charging shift ends by blasting the ore. The next shift loads and hauls the blasted ore, while a drilling crew prepares to blast in another location. Loose ore is loaded using Caterpillar 988B and 988C front end loaders equipped with 10 ton capacity buckets. The loaders fill 1 or two Caterpillar 631D 50 ton capacity haul trucks. These trucks haul the ore from the stope to one of two 5000 ton ore pockets located near shaft 30 for dumping. Depending on the distance to the ore pocket, the average time to remove, or muck, the blasted ore is 2 to 3 hours. Haul roads in the mine are maintained by a grader. Road surfaces are made of mine development rock crushed to less than 2 inches.

Primary crushing is done underground at Fletcher. The 5000 ton ore pockets feed down a chute to an Allis-Chalmers 32 by 42 inch jaw crusher. Output from the crusher is less than 6 inches in diameter. The crushed ore is fed into a measuring hopper; the hopper empties into one of two 8.5 ton ore skips, which carry the ore to the surface. The skips make a total of 30 trips per hour. At Fletcher, the ore hoisting operation is automatic. Each ore skip empties from the bottom into the 1,000 ton ore bin located on the west side of the mill building along side the headframe of shaft number 30.

2.2.2 Mill Operation

The mill operates 6 days a week, 3 shifts each day, beneficiating up to 5,000 tons of ore per day. The surface operation employs 15 people. The staff includes a mill superintendent, metallurgist, technician and a sample man; each shift has a foreman, operator, and 2 helpers.

The ore from the mine contains an average of 5.5 percent galena, 1 percent sphalerite, 0.3 percent chalcopyrite, and 3 percent moisture. Doe Run estimates that current water usage in the mill averages 2000 gpm (2.9 million gallons per day (GDP)). Mill water is supplied by the 2 million gallon reservoir located 400 feet west of the mill complex. The reservoir is supplied by water recycled from the tailings impoundment. Mine water is added as necessary as makeup, however, the bulk of the mine water is discharged to the mine water pond. Based on ratios established in the

USGS Mining and Reclamation Plan, clarified tailings water is currently pumped to the mill water reservoir at a rate of 1,350 gpm (1.9 million GPD).

The Fletcher mill process is described as a highly automated 3 step process consisting of crushing and grinding, flotation, and filtering of the final concentrates (Figure 2-5). Crushed ore from the 1,000 ton storage bin is delivered by conveyor belt to a screen that separates feed into greater than and less than 0.75 inches (2 cm) fractions. The oversize material is fed into the secondary crusher (Hydrocone type; no water added) and crushed to less than 1 inch (2.65 cm). Dust generated by the crusher collects in a sump and is returned to the mill circuit. Undersize material from the screen and the secondary crusher drop to a common belt feeding the rod mill feed box. Through-put to the rod mill ranges between 200 to 250 tons per hour. Sumps are located below the lead, zinc, and copper flotation circuits and collect any spills or water generated by the mill. Each sump returns solution back to its corresponding flotation circuit.

2.2.2.1 Grinding

Crushed ore, water, and the first reagents (zinc sulfate [1], depressant; xanthate [2], collector; and sodium cyanide [6], depressant) are mixed before entering the rod mill. Numbers in brackets correspond to locations on the flow sheet (Figure 2-5) where reagents are added; Table 2-1 describes the function of the reagent and the nominal quantity used. The rod mill is an Allis-Chalmers, 12 feet in diameter and 15 feet long. Output from the rod mill enters a sump where additional water is added. A pump transfers the ore slurry to 2 cyclone classifiers. A particle size monitor controls the feed to the flotation circuit (cyclone overflow); the cyclones pass 55 percent -200 mesh. Underflow material from the cyclones can be routed in one of two ways, either directly to the ball mill feed or the "Skim Air" unit. Typically, cyclone underflow material is routed to a ball mill (Allis Chalmers, 14 feet in diameter and 16 feet long). Output from the ball mill enters the sump shared with the rod mill and is returned to the cyclones. Particle residence time in the grinding circuit ranges from 10 to 15 minutes, requiring an average of 2.5 passes before passing to the flotation cells. The slurry contains about 45 percent solids and exits the grinding circuit at approximately 235 tons per hour.

The Skim Air or flash flotation machine is designed to beneficiate high-grade galena minerals from the cyclone underflow before additional grinding, while the particles are still quite large. In normal grinding circuits minerals with high specific gravity would be returned to the ball mill. The system is used infrequently at Fletcher. When operating, it makes a particle size cut that is more than 65 percent -200 mesh, primarily separating large galena particles and some copper (both referred to as values) from the finer mineral values and gangue. The froth, or heads, containing coarse values is sent directly to the lead-copper conditioner cells, further along in the flow sheet (Figure 2-5). Tailings from the skim air system are returned to the ball mill feed.

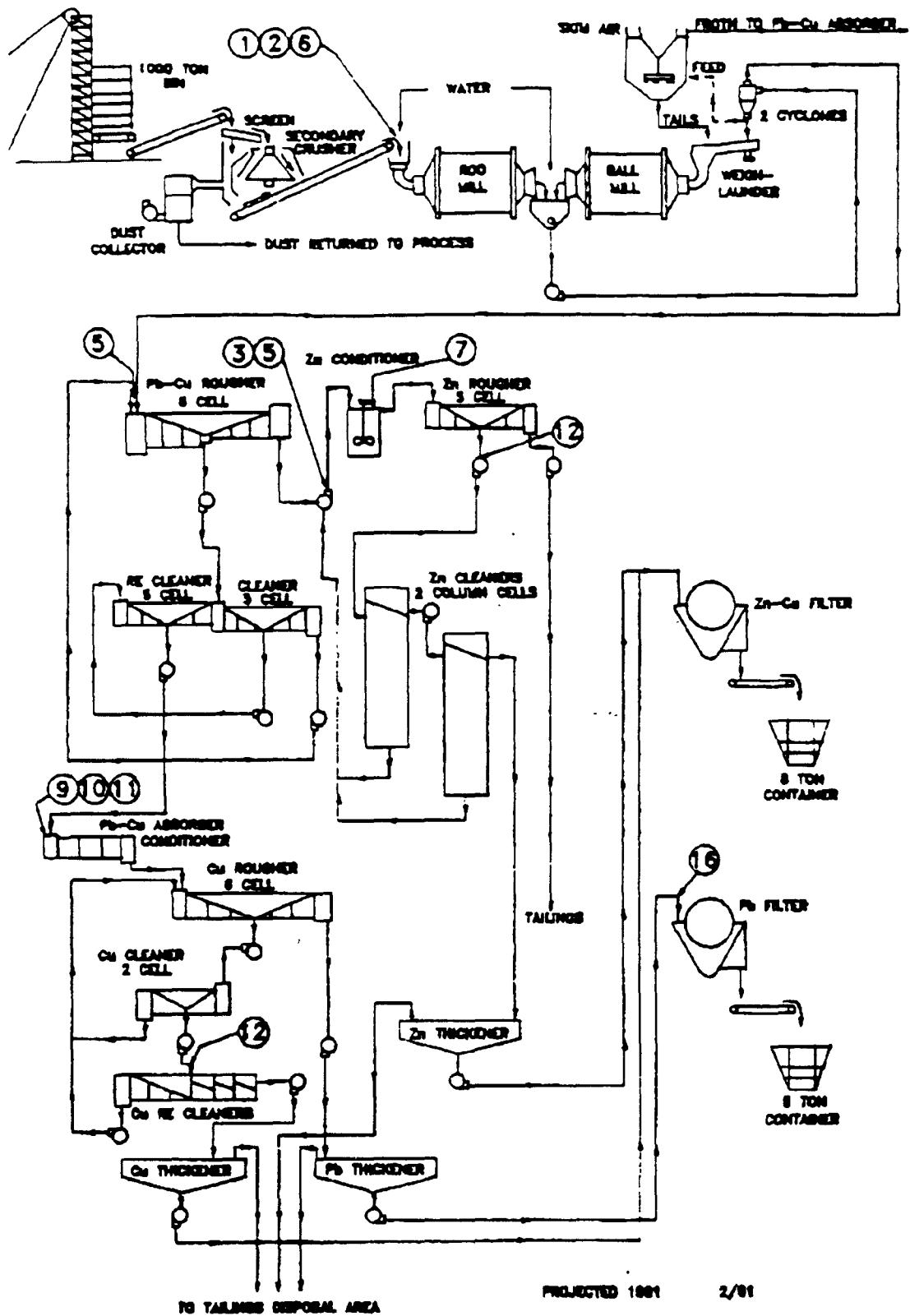


Figure 2-5. Fletcher Mill Flowsheet

(Source: The Doe Run Company)

Table 2-1. Flotation Reagents, Their Function, and Usage at the Fletcher Mill

FLOWSHEET LOCATION	CHEMICAL	FUNCTION	USAGE	
			LBS/TON ¹	TONS/YEAR ²
1	Zinc Sulfate	Depressant for sphalerite	1.600	960
2	Sodium Isoprophyl Xanthate	Primary collector for galena and sphalerite	0.70	857
3	Isoprophyl Ethyl Thionocarbamate	Collector for sphalerite and chalcopyrite	0.010	6
5	Mixed Alcohol	Frothing agent	0.050	30
6	Sodium Cyanide	Mineral depressant	0.002	1
7	Ammoniated Cupric Chloride	Activator for sphalerite	0.210	126
9	Sulphur Dioxide	pH regulation for copper flotation	0.600	360
10	Starch	Lead depressant	0.090	54
11	Caustic Soda	Mixed with starch	0.030	18
12	Sodium Dichromate	Lead depressant in copper flotation circuit and zinc circuit	0.057	34
16	Sodium Dioctyl Sulfosuccinate	Filter aid to improve concentrate dewatering	0.140	8

(Source: The Doe Run Company)

¹Based on nominal usage per short ton.

²Annual Consumption: nominal usage * average mining rate of 1.2 million short tons per year.

2.2.2.2 Flotation

Flotation consists of 3 steps -- roughers, cleaners, and re-cleaners -- each producing a higher grade of concentrate than the preceding step. Each step in the flotation process produces a froth, and tailings. Reagents are used throughout the process to separate metal values from gangue and one metal from another. Ore slurry from the cyclones enters a feedbox, a frothing agent [5] is added and the solution flows to the lead-copper roughers. These make the first cut by separating lead and copper from zinc and gangue minerals. The roughers are composed of six 500 cubic foot Denver flotation cells, with a junction box between the 3rd and 4th cell. Rougher cells use agitators powered by electric motors to keep the slurry suspended and inject air to provide bubbles for collection of lead and copper values. The froth flows over the lip of the cells into launder where a water spray is used to collapse the lead and copper-laden bubbles and form a slurry.

This slurry is pumped to the lead-copper cleaning circuit. Tailings from the lead-copper roughers exit the cells and are pumped to the zinc conditioner, located at the head of the zinc circuit. The lead-copper cleaners and re-cleaners are in series with each other. Froth containing lead and copper concentrates from the roughers enters the cleaner circuit. The cleaner and re-cleaner circuits consist of 5 cells each. Both types of cleaners use agitation only; air is provided by the vigorous agitation motion. Froth from the cleaner is pumped to the re-cleaner; tailings are pumped back to the distributor that feeds the lead-zinc roughers and passed through the system again (Figure 2-5). The tailings contain fugitive lead and copper minerals as well as zinc and gangue minerals. In the re-cleaner a higher grade lead-copper concentrate froth is collected in the launder and pumped to the lead-copper absorber-conditioner; tailings pass to the cleaner cells. The conditioner consists of 3 cells and functions to mix to the following reagents, a pH adjuster [9], depressant [10], and starch [11]. The conditioned concentrate is passed to the copper rougher. The pH of the conditioned pulp is 4.8. This is also the point in the flotation circuit where concentrate from the Skim Air system would enter the flotation circuit.

The copper rougher consists of 6 cells; agitators are used with air injection to produce a froth of copper concentrate and a tailing of lead concentrate. Lead concentrate is pumped to the lead thickener. The copper concentrate is pumped to the copper cleaner. Froth from the copper cleaner is passed to the re-cleaners. Tailings are pumped back to the copper rougher and passed through this sub-system again.

Between the copper cleaner and re-cleaner, a lead depressant [12] is added that further refines the copper froth produced by the re-cleaners. Copper concentrates from the re-cleaners are collected and pumped to the copper thickener. Tailings from the re-cleaners are returned to the copper rougher.

The Fletcher zinc circuit was in the process of being updated during the site visit. New rougher cells were being installed and are now on line. A new system of column cells is to replace existing cleaner

cells. These cells are projected to improve zinc recovery by 2 percent, up to a total recovery of 80 percent. They will not use mechanical agitators to suspend the feed. This discussion will focus on the zinc circuit as it existed during the site visit.

The zinc feed pump box pumps tailings from the lead-copper rougher cells composed of dolomite, zinc, and water as well as tailings from the zinc cleaners along with additional frothing agent [5] and an activator for sphalerite [7] to 5 zinc rougher cells. A lead depressant [12] is occasionally added to the float from these cells before they are pumped to the zinc cleaners and re-cleaners. The depressant minimizes the amount of lead passing with the zinc concentrates in the cleaners. Tailings from the rougher cells exit the mill to the tailings impoundment. The zinc flotation circuit uses a cleaner and re-cleaner similar to the lead-copper system; however, in the current system a re-re-cleaner is used to produce a higher quality concentrate. The zinc float concentrate is pumped directly to the zinc thickener. Tailings from the cleaner cells are returned to the conditioner tank and travel back through the system.

Each of the concentrates are pumped to a Eimco thickener that functions as a solid/liquid separator. The copper tank is 30 feet in diameter and 14 feet deep. The zinc tank is 40 feet in diameter and 14 feet deep. The lead tank is 50 feet in diameter and 14 feet deep. Rakes in the bottom of the tank move the concentrates toward a center point in the tank. Underflow from the thickeners is pumped to the filtration circuit at 70 to 75 percent solids. Water is recovered from the top of the tank and returned to the tailings impoundment.

The tailings exit the flotation circuit from the zinc rougher cells by gravity. Composite samples of the tailings for each shift during 1989 and 1990 were analyzed using atomic adsorption and wet chemistry; from these samples a yearly composite is maintained. Typically, the tails contain 52 percent dolomite, 0.11 percent lead, 0.02 percent zinc, 0.02 percent copper, and 40 percent water by volume. Other constituents include iron and sulfur minerals passing the flotation process. Tailing solution pH is 7.8 as it exits the mill.

2.2.2.3 Filtration

Two disk filter systems are in use at Fletcher. A 4 disk model receives concentrates from either the zinc or copper thickeners. When changing back and forth between zinc and copper the disk filter unit is cleaned prior to use. Due to the low copper content in the ore, copper concentrates are filtered approximately once each week. An 8 disk unit is used continuously to filter lead concentrates. Concentrates enter the filtration units containing 75 percent solids and exit containing 92 percent. The disk filters operate on a vacuum – the disks pull water through the filter allowing concentrates to accumulate on the surface. As a portion of the disk emerges from the tank, a burst of air inside each disk knocks the material off and into a hopper and onto a conveyor belt positioned below each of the

disk filters. The belt empties into an 8 ton concentrate box stationed on one of 2 turntables. Each turntable is equipped with 8 concentrate boxes.

Concentrates are shipped from the Fletcher mill by truck under contract with Doe Run. Drivers are trained in the use of the overhead crane used to lift and empty bins into an open-top truck, a cover is placed on the truck before leaving the mill. The loading process is completed inside the mill building. Lead concentrates are transported to the Doe Run Herculaneum smelter in Herculaneum, Missouri; zinc is sent to Sauget, Illinois and Bartlesville, Oklahoma. Copper concentrates are trucked to Bussen Quarry where they are stored before being shipped overseas.

2.2.2.4 Process Control

Automation at Fletcher is most visible in the control room. In the past the mill processes were controlled with a long bank of switches and indicator lights. These are now being replaced with a Proscon Process Control and Management System, a Courier 30 On-Stream X-Ray Analyzer, and an Expert Display System. The Proscon control system monitors 12 direct control loops for reagent and tonnage addition and 4 separate control loops monitor grinding. In addition, 16 analog and 16 discrete inputs monitor other points in the process. The facility plans to add air control, pulp level, and discrete motor control to the Proscon system (Jones et. al., 1991).

The Courier 30 X-Ray Analyzer samples the ore fed to the flotation cells, lead slurry, lead tailings, zinc slurry, copper slurry, and final tailings every 10 minutes. Pumps transfer sample slurry from each point in the process to the analyzer. Between samples water flushes the sample port clean. Solutions from each of the 5 sample streams are analyzed by X-ray fluorescence. A spectrometer and proportional counter determine relative concentrations of lead, zinc, copper, and iron. Data generated are in percent concentration of each in the respective sample streams.

An Expert Display System presents every aspect of the mill process flow, integrating information from the Courier 30 and other variables monitored by the Proscon equipment. Presets, or master controls, determine reagent use and other variables. Based on information collected throughout the process the Proscon system or the operator (manually) can make adjustments to reagent flow rates and other variables to maximize recovery. Along with the concentration information obtained from the X-Ray unit, the Expert Display shows the rate of reagent consumption in cubic centimeters per minute. This information is aggregated into a daily report for the mill. An example of the computer printout for the Fletcher mill from September 23, 1991 is presented in Figure 2-6.

The report shows recoveries of lead and zinc from the ore feed to be 97.22 percent; and 76.29 percent, respectively. Because of the low copper content in the feed assays, the copper circuit was not running on this day. Usage of reagents in this daily report are all greater than those presented in Table 2-1 since they represent wet reagent usage.

DAY ENDING
24-SEP-91 06:30

ROD MILL RUN TIME: 11.40 HRS
TONS MILLED (WET): 2645 TONS
MILLING RATE: 232.1 TPH

Z OPERATING TIME: 47.5
Z COPPER CIRCUIT ON: 56.0

	ASSAYS				DRY TONS PRODUCED	RECOVERIES			
	ZPB	ZZN	ZCU	ZFE		ZPB	ZZN	ZCU	ZFE
FEED	6.07	0.46	0.08	1.52	2566.1				
PB CONC	91.07	0.72	0.46	1.51	170.2	97.22	9.87	37.51	6.51
ZN CONC	3.89	54.79	1.14	2.66	14.5	0.37	76.29	8.63	1.42
CU CONC	4.14	0.23	29.67	27.62	0.0	0.00	0.00	0.00	0.01
TAIL	0.21	0.15	0.05	1.52	2383.8	2.46	13.75	52.58	91.79
					2568.6				
BACK CALCULATED									
BULK CONC	81.32	0.62	0.45	1.39	7.3	TPH			
ZINC FEED	0.66	0.46	0.06	1.53	102.7	TPH			

PB REAGENTS			ZN REAGENTS			CU REAGENTS		
	cc/min	lb/ton		cc/min	lb/ton		cc/min	lb/ton
XANTHATE	313	1.53	3894	12	3.24	STARCH	4103	2.51
ZNSO4	1151	345.60	CUSO4	108	36.15	DICHROMATE	368	0.56
NACN	58	0.0083	DICHROMATE	484	6.43			
FROTHER-PB	60	0.061	FROTHER-ZN	37	0.040	pH/SO2	5.67	

	MINIMUM ASSAYS					MAXIMUM ASSAYS			
	ZPB	ZZN	ZCU	ZFE		ZPB	ZZN	ZCU	ZFE
FEED	3.44	0.11	0.04	0.43		9.46	0.81	0.14	1.93
PB CONC	75.37	0.34	0.09	0.96		82.77	1.74	1.05	6.44
ZN CONC	1.67	48.86	0.67	0.58		7.02	57.89	4.38	7.42
CU CONC	3.45	0.20	29.42	27.47		4.15	0.25	30.18	27.96
TAIL	0.10	0.03	0.01	0.82		1.90	3.70	0.14	1.74
RECOVERIES	94.42	26.40	0.00	0.0	TPH	97.90	84.50	16.01	264.2
									TPH

COURIER 30	PB	ZN	CU	FE	SO	PB	ZN	CU	FE	SO
NORM FACTOR	0.9677	0.9832	0.9327	0.9800	0.9396	1.0571	1.0544	1.0386	1.0413	1.0338
H2O DIAGNOS	17.3	10.9	5.8	7.3	68.7	251.5	73.5	27.2	30.2	1380.7

Figure 2-6. Fletcher Mill Daily Report

(Source: The Doe Run Company)

2.3 WASTE MANAGEMENT

2.3.1 Types of Waste

Large volumes of wastes generated by the Doe Run Fletcher facility include tailings, and waste rock. Tailings from the mill consist of gangue, reagents and water and are transported as a slurry by pipeline for disposal in the tailings impoundment. Approximately 4,500 tons of tailings are generated per day containing 2.9 million gallons of mill water. The composite analysis of final tailings presented in Table 2-2 show small quantities of lead, zinc, and copper and increasing amounts of manganese, iron, and oxides of magnesium and calcium.

Waste rock, also known as mine development rock, is crushed underground using a portable crusher. The crushed rock is used in the mine for road surfacing material. The quantity of waste rock generated is not known.

Mine water is pumped from the mine at approximately 3,200 gpm and piped to the mine water pond. It is subsequently discharged into local surface water. Sampling data generated for the Fletcher NPDES permit show suspended solids, pH, lead, zinc, copper, and cadmium to be below limits set in the permit for the period January 1990 through April 1991. Smaller volumes of other wastes generated onsite include sanitary sewage, laboratory wastes generated during mill solution testing, waste oil and other lubricants, used tires and refuse.

2.3.2 Tailings

Tailings from the mill are generated at the rate of approximately 4,500 tpd or 1.4 million tons per year. They are disposed of in the tailings impoundment. The Fletcher tailings impoundment lies in the lower reaches of West Fork Hollow (Figure 2-2). It covers an area of 270 acres and has a drainage area of 902 acres above the main dam. The Dam is permitted by the Missouri Department of Natural Resources (DNR) Dam and Reservoir Safety Council, permit number MO-30160.

The dam is composed of earthen materials, rock, and coarse tailings. A report prepared by the USGS shows that the dam has an earthen core 30 to 35 feet high composed of native clay soils (USGS, Vol. II, 1981). A coarse rock filter blanket on the downstream face of this core drains water into the seepage collection pond. The dam is 2500 feet long. Its height has been increased to accommodate the increasing volume of storage needed. The height is increased using coarse tailings; fine tailings are added to the inside face as a seal. A cyclone is used to sort the tailings before depositing them. The downstream face is maintained at approximately a 3:1 slope. Missouri adopted construction guidelines, including earthquake requirements, in 1981. Since the dam was built before Missouri adopted construction guidelines, the dam has not been evaluated with earthquake loading. The elevation of the dam was 1,105 feet above mean sea level (MSL) as of February 1990. At that time plans called for increasing the height of the dam 40 feet to accommodate the remaining tailings

Table 2-2. 1989 and 1990 Tailings Composites, Fletcher Mill
(All values in percent unless noted.)

1989 COMPOSITES												
	Pb	Zn	Cu	Fe	Co	Ni	Ag oz/ton	CaO	MgO	Cd	Mn	S
Lead Concentrate	77.11	1.08	0.50	1.13	0.055	0.073	1.07	1.69	0.96	0.019	0.015	14.1
Copper Concentrate	3.32	0.23	31.25	28.20	0.59	0.75	0.84	0.27	0.17	0.004	0.004	34.1
Zinc Concentrate	1.91	57.32	0.59	2.40	0.127	0.133	13.05	2.04	1.40	0.89	0.016	31.1
Final Tails	0.23	0.22	0.11	1.70	0.012	0.013	0.109	27.8	19.6	0.004	0.292	0.10

1990 COMPOSITES													
	Pb	Zn	Cu	Fe	Co	Ni	Ag oz/ton	CaO	MgO	Cd	Mn	S	As
Lead Concentrate	78.47	0.98	0.41	0.92	0.052	0.075	1.02	1.55	0.86	0.017	0.012	0.065	0.044
Copper Concentrate	3.34	0.25	30.70	27.65	0.77	1.02	0.92	0.33	0.20	0.004	0.003	0.037	0.19
Zinc Concentrate	2.37	58.35	0.32	2.15	0.070	0.076	11.57	1.61	0.89	0.86	0.012	0.012	0.01
Final Tails	0.18	0.15	0.10	1.59	0.009	0.013	0.100	24.0	19.6	0.001	0.298	0.008	N/A

Source: The Doe Run Company

through 2005. The spillway elevation was 1,093 feet MSL and is regulated under the Fletcher NPDES permit as outfall 002. No discharges from this outfall are reported in the information available for this report.

Since the start of operations in 1965 the configuration of the impoundment has changed to accommodate additional tailings. Also the height of the dam has been raised several times. Originally, the mine water pond was located above the tailings impoundment near the mill. The mine water pond was moved to its current location in 1976 (See Figure 2-2). Either one or two tailings dams were located below the previous mine water pond; however, this could not be confirmed since records for the site were not available. The current tailings impoundment covers any earlier dams.

As part of the Fletcher Project Application for Metallic Minerals Waste Management Area Permit prepared by SRK, groundwater monitoring in the area around the tailings impoundment was conducted by Hydro-Search, Inc. Their report is based on information collected from 4 monitoring wells installed in 1987 and sampled in 1988. Well locations are identified in Figure 2-2. Monitoring well F-1 is upgradient of the facility, located in the Potosi ground-water. Wells F-2 and F-3 are downgradient, located below the tailings dam; well F-4 is near the spillway. The available data for these wells is presented in Table 2-3. Data for 1988 show that total dissolved solids, lead, manganese, and sulfate concentrations at F-2 and F-3 and iron in F-3 exceed the EPA primary drinking water standards. Data from well F-2, in the shallow ground water, show concentrations of heavy metals including cobalt, copper, nickel, lead, and zinc to be higher than those for the upgradient well F-1 in bedrock. Chromium was also found in Well F-3. Hydro-Search reported that results of the initial samples from wells indicated downgradient water in both the bedrock and alluvium were impacted by the tailings impoundment. The report recommended that wells F-2 and F-3 should be sampled bi-annually for TDS, major ions, cadmium, and the metals listed above (Hydro-Search, 1990).

As part of the permit with DNR, quarterly inspections of the dam are required. The quarterly reports for the first two quarters of 1991 prepared by E. George Tapp and William G. Huffman indicate that the top of the dam had several erosion gullies. The reports indicate that the erosion problem was first observed in August 1989. By the second quarter of 1990, all of the contour terraces on the face of the dam were cut or breached by erosion gullies.

In the August 30, 1991 Report it is noted that Drury Construction was recontouring the downstream face of the dam. The phreatic levels within the dam are routinely monitored, as is the seepage into the seepage return pond.

In April 1990, concurrent with their tailings dam permit renewal, Doe Run submitted a request to the DNR Dam and Reservoir Safety Program for approval of a phased expansion of the tailings dam. SRK prepared the engineering report; a copy was not available for this report. The permit was issued

Table 2-3. Water Chemistry Data for Monitoring Wells

Parameter	Upgradient ²	Potential ³	Flat. Rec. Pond	Downgradient Water Well Registration						Field Blank 4/87	
	Potest Ground-Water	Flat. Tall. Pond		F-2		F-3		F-4			
				4/87	5/88	4/87	5/88	4/87	5/88		
LAB DATA											
pH	7.8	7.1	6.9	7.5	6.9	7.2	7.1	6.7	6.1	7.3	
CONDUCTIVITY	337	1500	4000	2750	9500	3000	11500	<10	75	<1	
Total Dissolved Solids (TDS)	257	1354	3534	2292	2340	2420	2890	48	42	116	
Fluorine (Fl)	0.12	<0.5	<0.5	0.9	<0.5	1.3	<0.5	<0.1	<0.1	<0.1	
Chlorine (Cl)	5.0	97	305	99	408	107	181	2	2.4	<1	
Sulfate (SO ₄)	13.5	1103	3452	583	1335	597	1601	4	<5	<2	
Nitrite (NO ₂)	--	--	--	4	--	24	--	<1	--	<1	
Nitrate (NO ₃)	--	--	--	<1	--	<1	--	<1	--	<1	
Bromide (Br)	--	--	--	1.5	--	1.6	--	<0.5	--	<0.5	
Sodium (Na)	5.75	33	75	54.0	52	77.0	68	1.0	1.0	<1	
Potassium (K)	0.68	0.4	10	7.8	6.6	6.0	7.7	0.5	3.5	<1	
Calcium (Ca)	40.2	158	445	240	350	270	400	10	12	<1	
Magnesium (Mg)	24.5	90	240	185	170	200	218	4	3	<1	
HARDNESS	200	764	2099	1410	1574	1697	1897	38	62	<5	
Bicarbonate	--	--	<0.005	220	--	270	--	50	--	<5	
Silver (Ag)	<0.005	<0.005	0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	
Cadmium (Cd)	<0.005	0.005	0.64	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	
Cobalt (Co)	<0.025	0.025	0.053	0.08	0.040	0.02	0.025	<0.005	0.007	<0.005	
Chromium (Cr)	<0.005	0.025	0.013	<0.007	<0.005	<0.007	0.012	<0.007	<0.005	<0.007	
Copper (Cu)	0.065	0.006	0.025	0.01	0.016	0.01	0.020	<0.005	0.012	<0.005	
Iron (Fe)	<0.025	0.025	1.2	<0.025	0.025	<0.025	0.031	<0.025	<0.025	<0.025	
Manganese (Mn)	<0.005	0.50	1.3	1.20	0.007	0.19	0.15	0.08	0.15	<0.005	
Nickel (Ni)	<0.025	0.14	<0.025	0.16	0.10	<0.025	0.042	<0.025	<0.025	<0.025	
Lead (Pb)	<0.025	<0.025	--	0.03	0.054	<0.025	0.030	<0.025	<0.025	<0.025	
Antimony (Sb)	--	--	40	<0.025	--	<0.025	--	<0.025	--	<0.025	
Zinc (Zn)	0.360	0.9	--	0.12	0.12	0.01	0.037	<0.005	0.11	<0.005	
Mercury (Hg)	--	--	--	<0.0002	--	<0.0002	--	<0.0002	--	<0.0002	
Arsenic (As)	--	--	--	<0.005	--	<0.005	--	<0.005	--	<0.005	
Selenium (Se)	--	--	--	<0.005	--	<0.005	--	<0.005	--	<0.005	
Chemical Oxygen Demand (COD)	--	--	--	--	3	--	4	--	5	--	
Total Suspended Solids (TSS)	--	--	--	--	14	--	10	--	96	--	
(FIELD DATA)											
Temperature (°C)	17.7	--	--	19	--	20	--	17	--	--	
Conductivity	--	--	--	2311	--	2409	--	4	--	--	
Alkalinity	--	--	--	170	--	213	--	27	--	--	
pH	--	--	--	6.8	--	7.1	--	5.8	--	--	

1. All values are given in milligrams per liter (mg/l), except pH (standard units), and conductivity (microamps/cm @ 25°C)

Analyses by Doe Run Company, Central Lab, Viburnum, Missouri.

2. Data from PEBCo (1983).

3. Data from St. Joe Minerals Corp., January, 1986, Composite Samples.

-- Not analyzed.

(Source: Hydro-Search, Inc., 1990)

June 12, 1990, contingent on the Company submitting (1) a plan to repair existing erosion on the face of the dam and preventing future erosion, and (2) specifications for the saddle dike. Doe Run submitted the plans and specifications in November of 1990. In January of 1991 the DNR Dam Safety Program notified the Company that their concerns were satisfied, thus completing the permit renewal process.

The first phase of construction will increase the height of the dam 15 feet to 1,120 feet MSL. The spillway will be raised from 1,093 feet MSL to 1,100 feet MSL. During the site visit of September 24-25, dam re-facing was complete and construction to raise the height of the spillway had begun. The cyclone used to sort coarse and fine tailings was being prepared for installation. The second phase is tentatively planned for 1996, and will raise the height of the dam an additional 20 to 25 feet.

Seepage from the bottom of the tailings dam is collected in a pond at the base of the dam where it is pumped back to the impoundment. The seepage collection pond is approximately 0.5 acres; its drainage area from the face of the dam is approximately 15 acres. As reported in the quarterly dam inspections, pumpback from the seepage collection pond to the tailings impoundment ranged from an average low of 103,000 GPD during the period February through March 1991, to an average high of 238,000 GPD during the period May through June of 1990. Doe Run personnel reported that the variation is due to seasonal changes. Pumpback for the period June through July of 1991 however, was 83,000 GPD. Surface discharge from the pond is regulated under the NPDES permit as outfall 003.

At closure four surface water bodies will remain in the tailings impoundment, one each located in the hollows to the east of the main West Fork Hollow drainage (Figure 2-2). Surface water from the upper reaches of the drainage area will drain to the pond closest to the mill site and flow through each of the succeeding ponds and then over the spillway. Rip rap will be used to control erosion where slopes exceed 3:1. Dry portions of the tailings will be vegetated. Seepage from the dam will be pumped back to the impoundment until flow stops or its quality improves to allow discharge into Bee Fork (SRK, 1990).

2.3.3 Mine Water

Water from the mine is pumped to the mine water pond at an average rate of 4.63 million gallons per day (MGD). The mine water dam was built in 1976 and is permitted through the DNR Dam Safety Program, permit number MO-31141. Its purpose is to clarify incoming mine water before discharging it to Bee Fork. According to the Application for the Metallic Minerals Waste Management Act, the mine water pond was designed to be converted from a water retention structure to a tailings impoundment. Revised estimates for tailings storage needs indicate this will not be necessary. At closure no water will flow from the mine, however, the shafts will most likely fill with

water to within 150 feet of the surface based on water levels in the upgradient monitoring well (well F-1, Hydro-Search 1990). Shafts will be sealed at the top of the Davis Formation and the surface.

The pond receives surface water drainage from the 570 acres above the dam. The dam is constructed of compacted earth fill taken from adjacent land. The surface area of the pond is 22.5 acres, with a storage capacity of 340 acre feet. The surface of the dam is 1,040 feet MSL, spillway elevation is 1,030 feet, and the normal outfall elevation is 1,024 feet. Surface discharge from the pond is to Bee Fork and is regulated under the NPDES permit as outfall 001. Discharge rates reported in the quarterly monitoring reports range from 2 to 5 MGD. As discussed above, sampling data for the period January 1990 through April 1991 generated for the Fletcher NPDES permit show suspended solids, pH, lead, zinc, copper, and cadmium to be below limits set in the permit. At closure pumping will stop and water input to the pond will be limited to direct infall precipitation and surface water runoff. A new equilibrium level is expected to be reached in 2 to 3 years; at that time the shore line will be landscaped and seeded. Discharge from the pond will continue to flow into Bee Fork.

2.3.4 Other Wastes

Sanitary sewage is disposed of in 3 septic tanks located along the north side of the mill building. Two of the tanks are capable of supporting up to 200 people, a third is described as a 500 gallon tank. Laboratory analyses are generally conducted at the Viburnum offices. Wastes generated at the Viburnum laboratory during ore assays and mill solution testing consist of dilute acids and are disposed of in the municipal sewer system. Used standard truck tires are sold to recyclers; tires from large machinery are not easily disposed of and are accumulating in a storage area on the west side of the tailings impoundment (numbers not provided). Refuse is transported and disposed of in the Viburnum City landfill (amounts not provided).

The number and volume of wastes regulated as hazardous at the Fletcher facility are small. Solvents, waste oil and other lubricants are picked up monthly under contract with the Safety-Kleen Corporation. For the six quarters ending July 1991 an average of 1,765 gallons per quarter of wastes described as petroleum naphtha (UN 1255; EPA D001) are shipped off site. In one case, sulfuric acid wastes generated when a tank was cleaned were picked up by contract hauler; however, details such as amounts, were not included in the lab analysis report. Other RCRA wastes such as old reagents, have been disposed of by CECOS International (again, amounts are not available).

An inspection of transformers and capacitors conducted in June 1990 identified 6 units containing PCBs underground. At this time only one unit containing PCBs remains underground; one unit remains in the shop and 4 in the mill building.

2.4 REGULATORY REQUIREMENTS AND COMPLIANCE.

2.4.1 State of Missouri

The State of Missouri Department of Natural Resources implements three regulatory programs that affect the Doe Run Fletcher operation. The Division of Environmental Quality has authority to implement the National Pollutant Discharge Elimination System (NPDES) program and the Metallic Minerals Waste Management Act that became law on August 28, 1989. The Division of Geology and Land Survey, Dam and Reservoir Safety Program is responsible for permitting and inspecting all dams greater than 35 feet in height.

2.4.1.1 Water Permit

The current NPDES permit for the Fletcher facility (MO-0001856) was issued by the Division of Environmental Quality June 30, 1989, and is effective for five years. The letter transferring the permit states that the NPDES permit is Fletcher's "new State operating permit, replacing all previous operating permits." Doe Run and the State agree that the current permit meets the new Storm Water requirements under NPDES.

The permit regulates surface water discharge at three outfalls from waste disposal facilities and a water quality compliance point in Bee Fork. Outfall 001 is the discharge from the mine water pond. Outfall 002 is for discharge from the seepage collection pond located below the tailings dam; outfall 003 is the tailings impoundment spillway. The tailings impoundment is designed to contain the 10-year 24-hour storm event. As determined by the United States Hydrologic map, this equates to 5.8 inches of precipitation. Rainfall exceeding this amount will flow over the spillway (NPDES outfall 002). The Water Quality Compliance Point (004) is located where the road below the tailings dam crosses Bee Fork (Figure 2-2). The Division of Environmental Quality conducts inspections of the outfalls and receiving stream annually.

The tailings impoundment is a zero discharge facility as specified by the permit; therefore, discharge from outfalls 002 and 003 is permitted only when precipitation exceeds the 10 year, 24 hour amount or as specified in the Ore Mining and Dressing Effluent Limitation Guidelines (40 CFR Part 440, Subpart J). Any discharge must meet effluent standards specified in the permit. However, if the Company is in compliance with the special conditions in the permit and a discharge from outfall 002 or 003 occurs, the Company need only monitor the discharge. Monitoring required under the special conditions includes water quality analysis at outfalls 001, 002, 003, and 004 each month; data is collected and reported to the Division of Environmental Quality quarterly. Monthly monitoring data for the 5 quarters ending in April 1991 show all samples to be in compliance with standards established in the permit. Data reported for outfalls 001 and 004 during the second quarter of 1991 are presented in Table 2-4. No discharges from outfalls 002 and 003 were reported in the period. Rainfall is monitored daily and Whole Effluent Toxicity is monitored once per year. All whole

Table 2-4. Water Quality Data for NPDES Outfalls 001 and 004, Second Quarter 1991
(Source: Quarterly Monitoring Report)

Surface Discharge from Mine Water Pond, Outfall 001						
PARAMETER	Final Limits	Results of Analysis			Sample Type	Analytical Method*
Flow MGD	no limits	2.52	4.01	3.71	Grab	Pygmy Flow Meter
Temperature Degrees F	no limits	61	75	75	Grab	
Suspended Solids mg/l	20.0	< 1	< 1	6.0	Grab	00530
pH units	6.0 - 9.0	7.8	7.9	8.5	Grab	00403
Oil and Grease mg/l	15.0	< 1	< 1	< 1	Grab	00556
Lead (Total) mg/l	.30	.056	.074	.065	Grab	01051
Zinc (Total) mg/l	.75	.024	.018	.010	Grab	01092
Copper (Total) mg/l	.15	< .005	< .005	< .005	Grab	01042
Cadmium (Total) mg/l	.05	< .002	< .002	< .002	Grab	01027
Mercury (Total) mg/l (once/year monitoring)	.001				Grab	71900

*EPA Storet Number

Water Quality Compliance Point, Outfall 004						
PARAMETER	Final Limits	Results of Analysis			Sample Type	Analytical Method*
Flow MGD	no limits	20.33	13.41	6.90	Grab	Pygmy Flow Meter
Lead (Tot. Rec.) ug/l	190	< 20	< 20	< 20	Grab	01049
Zinc (Tot. Rec.) ug/l	490	< 5	< 5	8	Grab	01090
Copper (Tot. Rec.) ug/l	37	< 5	< 5	< 5	Grab	01040

*EPA Storet Number

Effluent Toxicity data submitted by the University of Missouri at Rolla satisfy the criteria established in the permit.

In June 1987 Doe Run requested DNR to modify their NPDES permit, allowing treatment and discharge of excess runoff as allowed under the Special Conditions in the NPDES permit and the Ore Mining and Dressing Effluent Limitation Guideline (Doe Run, 1987a). Similar requests were made by the St. Joe Minerals Corporation in 1985 and 1986. They proposed to modified their piping system to pump water from the tailings impoundment to the mine water pond for treatment and disposal. According to the DNR this change would require Doe Run to submit a new NPDES permit application; however, no correspondence to this effect was obtained.

In a letter dated November 3, 1987 Doe Run notified the DNR that the Fletcher facility began production on November 2, 1987. The letter also stated that pumping from the tailings impoundment to the mine water pond began on June 6 and ended November 2, 1987 with a total of 400,000,000 gallons pumped (Doe Run, 1987b). This volume is approximately 60 percent of the total discharge from the mine water pond through outfall 001 for the five month period. Monitoring data for the NPDES permit show no significant change in quality during this time.

Doe Run stated that water discharged through the NPDES point met BAT Effluent Limits for mine and mill water at all times, and that in the future pumping would not exceed an amount equal to the annual precipitation minus annual evaporation. The Company stated that water being discharged through the NPDES compliance point would be monitored on a weekly basis to meet BAT limits. No additional communication between Doe Run and the DNR concerning this matter is available until a letter was sent by Doe Run on August 31, 1990. In this letter, Doe Run makes a similar request to DNR to pump tailings water to the mine water pond for treatment and disposal. No additional correspondence was available for this report. Doe Run applied for a renewal of their NPDES permit in January 1988. DNR issued an NPDES permit in June of 1989. In neither the application nor the permit was there mention of the request to divert water from the tailings impoundment to the mine water pond; however, the special conditions of the permit did cite the Ore Mining and Dressing Effluent Limitation Guideline.

In May of 1987 and again in 1990 Doe Run reported to the DNR that water was discharged from the seepage collection pond (outfall 002) directly into Bee Fork. In both cases this was due to heavy rains exceeding the capacity of the pumps and/or pump failure. The Company reported that daily inspections discovered the problem and they were studying ways to install an alarm system to give advance warning of problems.

During an inspection by DNR personnel in May of 1991 a black stain was observed on the stream bottom of Bee Fork where mine water effluent mixes with the stream. In the inspection report DNR asked Doe Run to report on the situation in 60 days. The Company responded by contracting with

the University of Missouri at Rolla to study the problem and prepare a report by December 1991. The results of their findings indicate that the black material is manganese, probably MnO_2 . Other constituents may include iron, cobalt, cadmium, lead, and zinc (Doe Run 1992). Based on data presented in the quarterly monitoring reports, discharge from the mine water pond through outfall 001 contributes up to 80 percent of the flow in Bee Fork during extreme low flow conditions.

2.4.1.2 Metallic Minerals Waste Management

The new Metallic Minerals Waste Management Act regulates disposal of waste from metallic mineral mining, beneficiation, and processing. Facilities must apply for a permit from the DNR Division of Environmental Quality. The application is to include a closure plan and an inspection-maintenance plan which will ensure the containment of metallic mineral wastes. Each of the plans must be coordinated with other environmental permits regulating water quality, air quality, solid waste disposal, and dam safety. Since this is a new rule, the Division of Environmental Quality Regional Office in Poplar Bluff is still in the process of implementation.

Doe Run submitted their Fletcher Project Application For Metallic Minerals Waste Management Area Permit in February of 1990. The application was prepared by SRK with support from Hydro-Search, Inc. concerning groundwater monitoring information required for the closure plan (SRK, 1990). A discussion of the groundwater monitoring reported in the Hydro-Search report is presented in the tailings discussion. Doe Run completed the application requirements including financial assurance documents. The application was re-written by McLaren/Hart and resubmitted to DNR. The State issued permit MM-009 to the Fletcher facility on January 13, 1992. All permit requirements, including financial assurance, have been met. A bill pending in the Missouri legislature, co-sponsored by DNR and the mining industry, may raise the annual fee to \$7,500.

2.4.1.3 Dam Safety

The DNR Division of Mines and Geology, Dam and Reservoir Safety Program has issued permits for the Fletcher tailings dam (MO-30160) and mine water dam (MO-31141). An annual inspection of these structures is required to verify the dams safety. As noted in the tailings impoundment discussion, inspection reports for 1989 and 1990 identified gully erosion on the face of the dam. This was repaired as part of the dam expansion project begun during the summer of 1991. No problems were identified with the mine water dam.

2.4.1.4 Other State Regulations

Construction permits were not required for facilities built before 1980. However, the State does require facilities to submit an Emissions Inventory Questionnaire (EIQ) annually. In conjunction with the EIQ, a State inspector conducts an annual inspection. The inspection conducted in January 1990 examined seven point sources and their control equipment. Sources having no opacity at the time of

inspection include: the ore lift/vent shaft, rod mill, concentrator building, and boiler #2. Sources having opacities less than 10 percent include the secondary crusher, boiler #1, and the haul roads. Control equipment includes wet scrubbers on the crusher and rod mill, and a surfactant spray on haul roads. The other point sources are not fitted with control equipment.

Missouri regulates storage of waste tires under RSMo 260.200 to 260.345 (1990). This regulation applies to facilities that store more than 500 whole, cut, chipped or shredded waste tires for more than 30 days. Doe Run does not store tires in this quantity, however, they did point out that disposal of the large tires is difficult. The State of Missouri issued Hazardous Waste Generator Identification No. 01096 to the Fletcher operation for waste oil only.

A violation was issued to Doe Run in August 1989 following an inspection of the drinking water system. The problem was thought to be related to mechanical difficulties and a high coliform bacteria count in samples taken from the facilities. As required, the Company issued a public notice and agreed to upgrade the drinking water system. The system was upgraded by the installation of a chlorination unit.

2.4.2 Federal Regulations

The surface facility at Fletcher is located on land owned by the Doe Run Company; however, much of the underground workings are on public lands managed by the Forest Service. The BLM has jurisdiction over mineral rights, the Forest Service manages the surface in Mark Twain National Forest. The BLM and, at that time, The St. Joe Minerals Company entered into the Fletcher development contract on June 12, 1970 for the purpose of mining lead, zinc, and copper in the Mark Twain National Forest. The main purpose of the contract was to delineate boundaries and establish ownership of lands in the area of the Fletcher project.

The Doe Run Fletcher Mine has two leases with the BLM totaling 5,980 acres. The Solid Mineral Leases BLM-A-047477 and BLM-A-049307 expire May 31, 1993. According to the BLM they will be renewed if the operation remains in production. A Prospecting Permit (ES-035967) was to expire on October 31, 1991; the BLM noted that this permit would be extended for an additional four years. Bonds for all of Doe Run's operations in Missouri are under one "Statewide" bond totaling \$1,405,000. The bond covers potential unpaid royalties, lease rental (\$1/acre/year), and surface reclamation (mainly from exploratory drilling and vent shafts)(BLM 1991). BLM and the Forest Service confer on issues concerning the lease; the Forest Service must review and approve lease terms. A general operating plan provides guidelines for activities on Forest Service land; a plan of operations is prepared for activities such as drilling a vent shaft. For surface activities on these lands, a letter of authority from the Forest Service is required. Activities in non-lease areas require a special use permit.

The Environmental Protection Agency prepared a Preliminary Assessment of the Fletcher Facility in August 1984 because EPA had reason to believe the mining wastes may be hazardous (EPA, 1984). The recommendation made was to conduct sampling on a low priority basis due to the presence of heavy metals and hazardous materials in the mine effluent. Sampling locations include sites downstream of the tailings pond in the West Fork Hollow and Bee Fork past the Fletcher property line. Background samples were suggested upstream in Bee Fork.

2.5 REFERENCES

- Allgood, Ferris P. and Ival D. Persinger. 1979. The Missouri General Soil Map and Soil Association Description, USDA Soil Conservation Service and Missouri Agricultural Experiment Station.
- BLM, September 30, 1991. Letter from Jeffrey Carroll, BLM, to Steve Hoffman, EPA on lease and bond information for the Fletcher Mine.
- Doe Run, January 1992. Black Rocks in the Black River or How do You Suppose the Black River Got Its Name? Prepared for Doe Run by Dr. Nord Gale and Dr. Barbara R. Patterson, University of Missouri-Rolla.
- Doe Run, February 1990. Fletcher Project Application for Metallic Minerals Waste Management Area Permit. Prepared by Steffen, Robertson and Kirsten, Lakewood Colorado.
- Doe Run, 1987a. Letter from John Carter, Doe Run, to Jim Burris, DNR, on June 10, 1987 informing the State that changes to the piping system to connect the tailings water to the mine water pond were underway.
- Doe Run, 1987b. Letter from John Carter, Doe Run, to Jim Burris, DNR, on November 3, 1987 providing information on the volume of water pumped from the tailings impoundment in the last 6 months (400,000,000 gallons).
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- Jones, James A. *et. al.*, December 1991. Process Control at Doe Run's Fletcher Concentrator. Mining Engineering, Vol. 43, Number 12, pages 1407-1411.
- Mineral and Water Resources of Missouri, 1967. Report of the United States Geological Survey and the Missouri Division of Geological Survey and Water Resources. Document No. 19 of the 1st Session of the 90th Congress.
- USGS Mining And Reclamation Plan, Volume II, Public Information, April 1981. Prepared for the St. Joe Minerals Corporation Fletcher Division by Impact Environmental Consultants, Ltd., 1409 Larimer Square, Denver Colorado 80202.

APPENDIX 2-A

**THE DOE RUN COMPANY'S COMMENTS ON THE
DRAFT SITE VISIT REPORT,
AND EPA'S RESPONSES**

EPA has revised the site visit report to incorporate all of the comments submitted by The Doe Run Company. In some cases, EPA made minor changes to wording as suggested by Doe Run in order to attribute the changes to the Company or enhance clarity. The Doe Run Company submitted comments in the form of a mark-up of the draft text. Their comments are summarized below.

- Comment 1: Page 1, paragraph 2; The Doe Run Company clarified the text concerning Company ownership.
- Comment 2: Page 4, paragraph 1; zinc concentrates are shipped to Sauget, Illinois and Bartlesville, Oklahoma. Copper concentrates are shipped over seas.
- Comment 3: Page 6, paragraph 2; The Doe Run Company has issued a lease to the Nature Conservancy to manage the surface in this area.
- Comment 4: Page 10, paragraph 1; Recovery rates for zinc are 80 percent.
- Comment 5: Page 10, paragraph 3; Individual buildings for storage of blasting caps and explosives have been removed. Blasting caps and explosives are now stored underground; there is an oil storage building on the surface. There is no equipment storage area on the west side of the tailings dam.
- Comment 6: Page 10, paragraph 4; Automatic grinding control and level-sensing devices. Also, 6 processes, not 5, are analyzed.
- Comment 7: Page 11, paragraph 1; Due to changes in metallurgy and automation, a 6 percent increase in concentrate quality was achieved at the mill, thereby reducing smelter slag volume and contaminant content during smelting.
- Comment 8: Page 11, paragraph 3; According to Doe Run personnel, an oil skimmer is used at each sump to remove any waste oil from the surface of the sump; at the time of the visit all 3 sumps were working.
- Comment 9: Page 11, paragraph 4; Air is pulled into the mine using Joy Axivane fans.
- Comment 10: Page 13, paragraph 1; Fletcher uses approximately 80 % ANFO; 20 % dynamite.
- Comment 11: Page 13, paragraph 2; Loose ore is loaded using Caterpillar 988B and 988C front end loaders equipped with 10 ton capacity buckets. The loaders fill 1 or two Caterpillar 631D 50 ton capacity haul trucks.
- Comment 12: Page 14, top of page; delete the following text: "Similarly, mine water is added at the rate of . . .[to end of paragraph]."
- Comment 13: Page 14, paragraph 1; Each sump returns solutions back to its' corresponding flotation circuit.
- Comment 14: Page 14, paragraph 2; Recommend the following changes to this paragraph: Crushed ore, water, and the first reagents (zinc sulfate [1], depressant; xanthate [2], collector; and sodium cyanide [6], depressant) are mixed before entering the rod mill. Numbers

in brackets correspond to locations on flow sheet (Figure 5) where reagents are added; Table 1 describes the function of the reagent and quantity used. The rod mill is an Allis-Chalmers, 12 feet in diameter and 15 feet long. Output from the rod mill enters a sump where additional water is added. A pump transfers the ore slurry to 2 cyclone classifiers. A particle size monitor controls the feed to the flotation circuit (cyclone overflow); the cyclones pass 55 percent -200 mesh. Underflow material from the cyclones can be routed in one of two ways, either directly to the ball mill feed or the "Skim Air" unit. Typically, cyclone underflow material is routed to the ball mill (Allis-Chalmers, 14 feet in diameter and 16 feet long). Output from the ball mill enters the sump shared with the rod mill and is returned to the cyclones. Particle residence time in the grinding circuit ranges from 10 to 15 minutes, requiring an average of 2.5 passes before passing to the flotation cells. The slurry contains about 45 percent solids and exits the grinding circuit at approximately 235 tons per hour.

Comment 15: Page 17, paragraph 1; Recommend the following changes to this paragraph: Flotation consists of 3 steps, roughers, cleaners, and re-cleaners, each producing a higher grade of concentrate than the preceding step. Each step in the flotation process produces a froth, and tailings. Reagents are used throughout the process to separate metal values from gangue and one metal from another. Ore slurry from the cyclones enters a feed-box, a frothing agent [5] is added and the solution flows to the lead-copper roughers. These make the first cut by separating lead, copper from zinc and gangue minerals. The roughers are composed of six 500 cubic foot Denver flotation cells, with a junction box between the 3rd and 4th cell. Rougher cells use agitators powered by electric motors to keep the slurry suspended and inject air to provide bubbles for collection of metal values. The froth flows over the lip of the cells into a launder where a water spray is used to collapse the metal-laden bubbles and forms a slurry.

Comment 16: Page 18, paragraph 2 and 3; Recommend the following changes to these paragraphs: The Fletcher zinc circuit was in the process of being updated during the site visit. New rougher cells were being installed and are now on line. A new system of column cells is to replace existing cleaner cells by May 1992. These cells are projected to improve zinc recovery by 2 percent. They will not use mechanical agitators to suspend the feed. This discussion will focus on the zinc circuit as it existed during the site visit.

The zinc feed pump box pumps tailings from the lead-copper rougher cells composed of dolomite, zinc, and water as well as tailings from the zinc cleaners along with additional frothing agent [5] and an activator for sphalerite [7] to five zinc rougher cells. A lead depressant [12] is occasionally added to the float from these cells before they are pumped to the zinc cleaners and re-cleaners.

Comment 17: Page 20, paragraph 1; Recommend the following changes to this paragraph: The report shows recoveries of lead and zinc from the ore feed to be 97.22 percent; and 76.29 percent, respectively. Because of the low copper content in the feed assays, the copper circuit was not running on this day. Usage of reagents in this daily report are all greater than those presented in Table 1 and no explanation for this is available at this time.

Comment 18: Page 22, paragraph 2; Currently, waste rock is crushed underground using a portable crusher.

- Comment 19: Page 24, paragraph 5; Recommend the following changes to this paragraph: In the August 30, 1991 report it is noted that Druy Construction was in the process of recontouring the downstream face of the dam. The phreatic levels within the dam are routinely monitored, as is the seepage into the seepage return pond.
- Comment 20: Page 26, paragraph 4; The range of seepage from the bottom of the tailings dam (average low of 103,000 GPD during the period February through March 1991, to an average high of 238,000 GPD during the period May through June of 1990) was due to seasonal changes.
- Comment 21: Page 27, paragraph 4; Recommend the following changes to this paragraph: An inspection of transformers and capacitors conducted in June 1990 identified 6 containing PCBs underground. At this time only one unit containing PCBs remains underground; one unit remains in the shop and four in the mill building.
- Comment 22: Page 29, end of the top paragraph; Recommend the following changes to this paragraph: Rainfall is monitored daily and Whole Effluent Toxicity is monitored once per year. All Whole Effluent Toxicity data submitted by the University of Missouri at Rolla satisfy the criteria established in the permit.
- Comment 23: Page 31, paragraph 1; It should be noted that discharge from the mine water pond amounting to 80 percent of the volume in Bee Fork occurs only under extreme low flow conditions.
- Comment 24: Page 31, paragraph 3; Add the following text to the end of this paragraph: The application was re-written by McLaren/Hart and resubmitted to DNR. The State issued permit MM-009 to the Fletcher facility on January 13, 1992. All permit requirements, including financial assurance, has been met. A bill pending in the Missouri legislature, co-sponsored by DNR and the mining industry, will raise the annual fee to \$7,500.
- Comment 25: Page 32, paragraph 3; Add the following text to the end of this paragraph: The system was upgraded by the installation of a chlorination unit.
- Comment 26: Page 33, paragraph 1; The following discussion concerning the Draft EIS is not relevant to the Fletcher facility and should be deleted: In 1987, the United States Departments of Agriculture and Interior (Forest Service and BLM) prepared a Draft Environmental Impact Statement for Hardrock Mineral Leasing in the Mark Twain National Forest, Missouri. The Final EIS was not available for this report. The analysis presented indicates that alternatives other than no action could have adverse effects on water resources through a risk of tailings impoundment failure or chronic leakage and visual impacts to the landscape caused by structures. The preferred alternative was a modified forest plan that avoided sensitive areas and minimized visual impacts while providing access to larger areas for exploration and development.

APPENDIX 2-B

**THE BUREAU OF LAND MANAGEMENT'S COMMENTS ON THE
DRAFT SITE VISIT REPORT,
AND EPA'S RESPONSES**

Comment 1: A review for consistency and technical wording is needed among figures referred to in the report. Examples include the reported volume of ore and tailings produced.

Response: The document has been edited for consistency and technical wording.

Comment 2: Where the report indicates that information is "not available", some clarification is needed.

Response: Wherever possible, information gaps in the earlier drafts of the report have been clarified.

Comment 3: Overall, we would like to see some conclusion or judgment incorporated into the report, if appropriate. Some context in which to evaluate the Fletcher facility would be helpful.

Response: EPA is gathering information to characterize mining waste and waste management practices. These site visits were designed to collect only factual information without making any qualitative assessments of environmental risks.

Comment 1: Page 22, paragraph 1; The technical discussion of reagent volume in the slurry is unclear.

Response: This statement has been deleted since it was not pertinent to the waste discussion.

Comment 2: Page 24, top of page; The text indicates that the dam does not meet Missouri's earthquake requirements since it was built before construction guidelines were adopted in 1981. This should be clarified in the text.

Response: The text has been revised as follows: Missouri adopted construction guidelines, including earthquake requirements, in 1981. Since the dam was built before Missouri adopted construction guidelines, the dam has not been evaluated with earthquake loading.

Comment 3: Page 24, paragraph 2; With the understanding that the report is not intended to draw any conclusions, there is concern about the implications of dissolved solids, sulfate concentrations, and some heavy metals in the monitoring wells. Some concentrations exceed EPA primary drinking water standards.

Response: EPA is gathering information to characterize mining waste and waste management practices. These site visits were designed to collect only factual information without making any qualitative assessments of environmental risks.

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APPENDIX 2-C

**THE FOREST SERVICE'S COMMENTS ON THE
DRAFT SITE VISIT REPORT,
AND EPA'S RESPONSES**